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Save ENERGY Now

Energy Efficiency for Ca States' Business Technology

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Agenda

Topic	Speaker
Welcome and Introduction	DGS & SMUD
Overview and Benchmarking	Bill Tschudi
IT	Bill Tschudi
Electrical Systems	Bill Tschudi
Break	
HVAC	Mark Hydeman
Liquid Cooling	Mark Hydeman
Lunch	
Retrofits	Mark Hydeman
Break	
Retrofits	Mark Hydeman
Wrap-up	Bill Tschudi

Handouts

- You can get a copy of the handouts in PDF format as follows:
  - Enter the following link into Internet Explorer: http://pub.taylor-engineering.com/
  - When prompted enter the following (case sensitive)
    - USER: seminar
    - PASSWORD: public
  - Double click on the folder, “Data Centers”
  - Double click on a file to download it or highlight the file and click on the download file icon
  - NOTE: YOU MUST USE WINDOWS INTERNET EXPLORER TO ACCESS THIS SITE!

Introduction

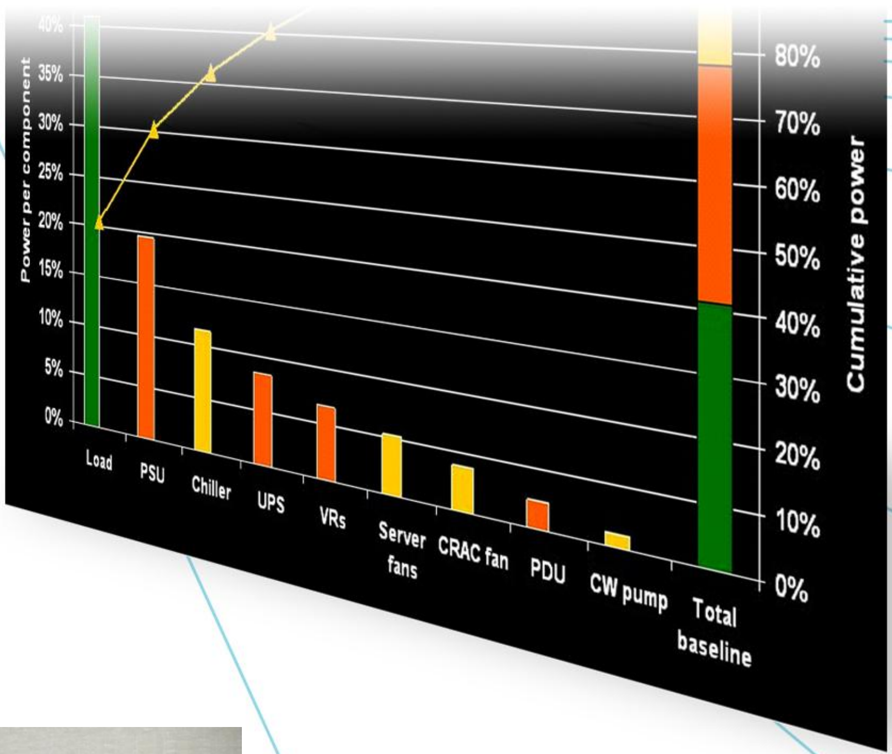
- Who are you?
  - Facility Operations
  - Facility Engineering
  - IT
  - Consultant
  - Contractor
  - Vendor
  - Other
- What brings you here?

Course objectives

- Raise awareness of data center energy efficiency opportunities
- Provide resources for on-going use
- Group interaction for common issues and possible solutions

What we will cover

- Major energy use in data centers
- Opportunities to increase computational efficiency and the multiplier effect
- Energy intensity growth
- Benchmarking
- Best practices to improve infrastructure efficiency
- Extending the life and effective capacity of existing data centers
- Technologies coming down the R&D pipeline and lessons learned from demonstrations
- Government programs
- Information and technical assistance resources



Introduction and Overview of Energy Use in Data Centers

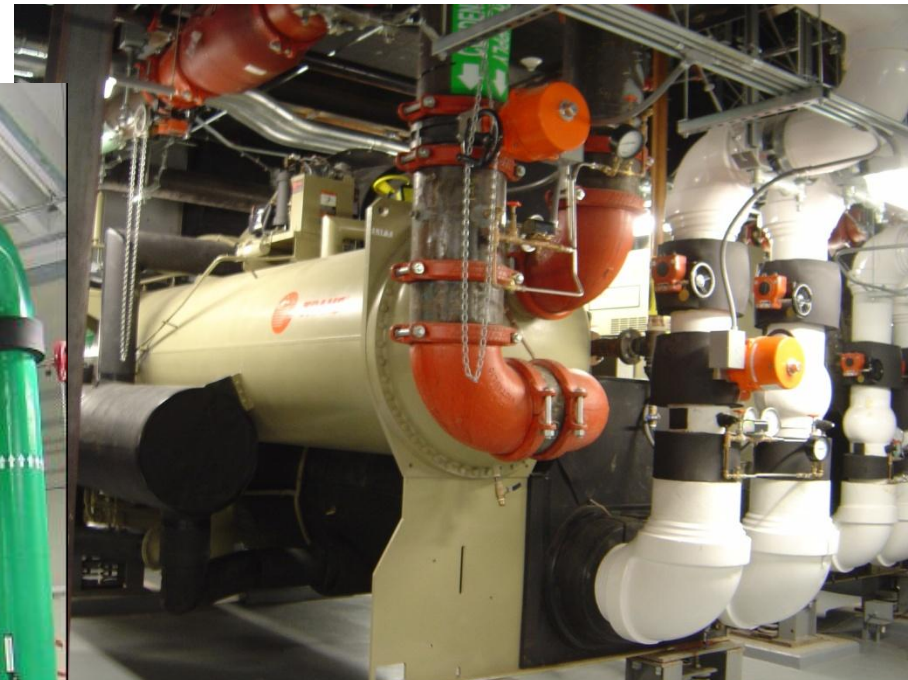
Bill Tschudi, PE

BERKELEY LAB

Data Centers are INFORMATION FACTORIES

- Data centers are energy intensive facilities
  - Server racks now designed for more than 25+ kW
  - Surging demand for data storage
  - Typical facility ~ 1MW, can be > 20 MW
  - Nationally 1.5% of US Electricity consumption in 2006
- Projected to double in next 5 years
- Significant data center building boom
  - Power and cooling constraints in existing facilities

Data centers…
resemble large industrial facilities



… with specialized equipment

Energy issues abound

- Over the next five years, power failures and limits on power availability will halt data center operations at more than 90% of all companies

  (AFCOM *Data Center Institute's Five Bold Predictions, 2006)*

- By 2008, 50% of current data centers will have insufficient power and cooling capacity to meet the demands of high-density equipment

  (Gartner press release, 2006)

- Survey of 100 data center operators: 40% reported running out of power, cooling capacity, and to a lesser extent - space without sufficient notice

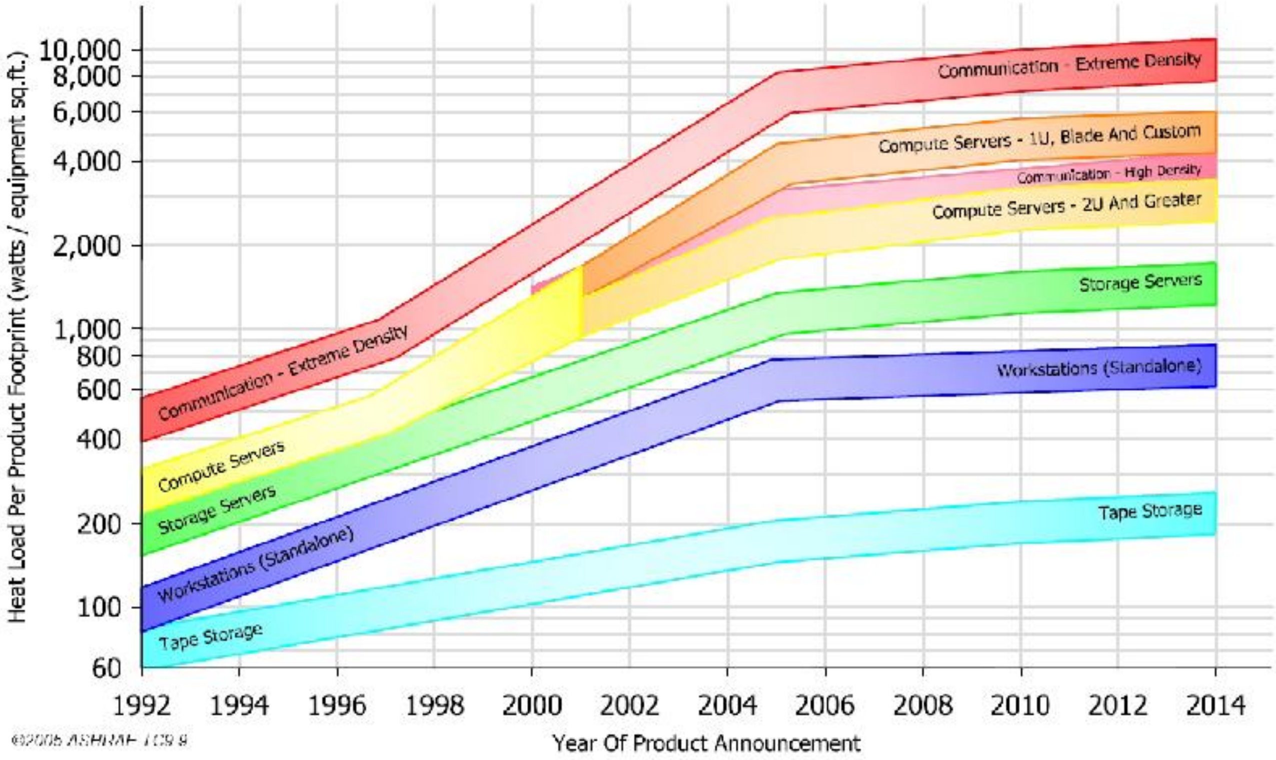
  (Aperture Research Institute)

The rising cost of ownership

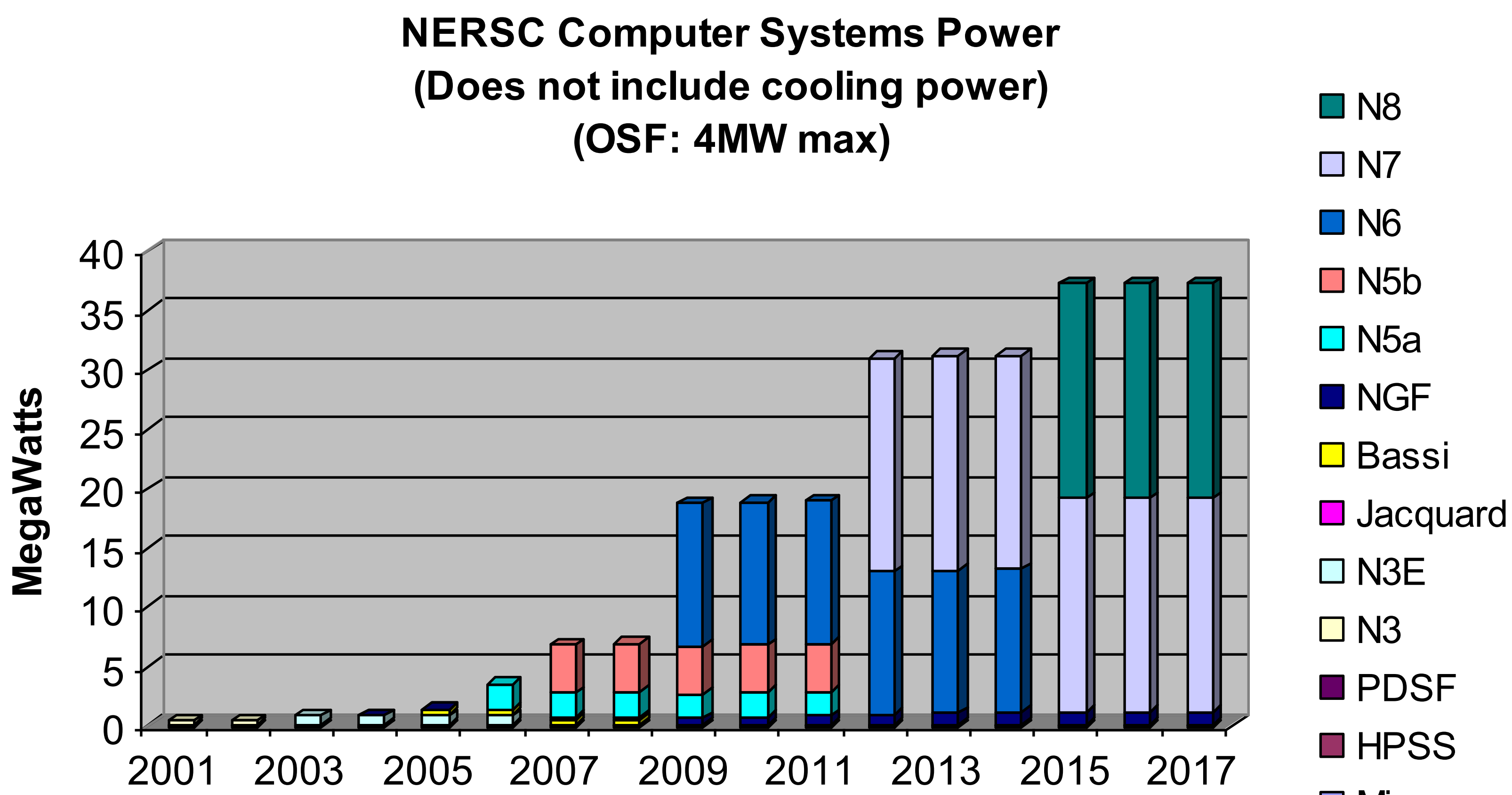
- From 2000 – 2006, computing performance increased 25x but energy efficiency only 8x
- Cost of electricity and supporting infrastructure now surpassing capital cost of IT equipment over its useful life
- Perverse incentives -- IT and facility costs are the responsibility of different parts of the organization

Source: The Uptime Institute, 2007

ASHRAE prediction of intensity trend



LBNL super computer systems power:



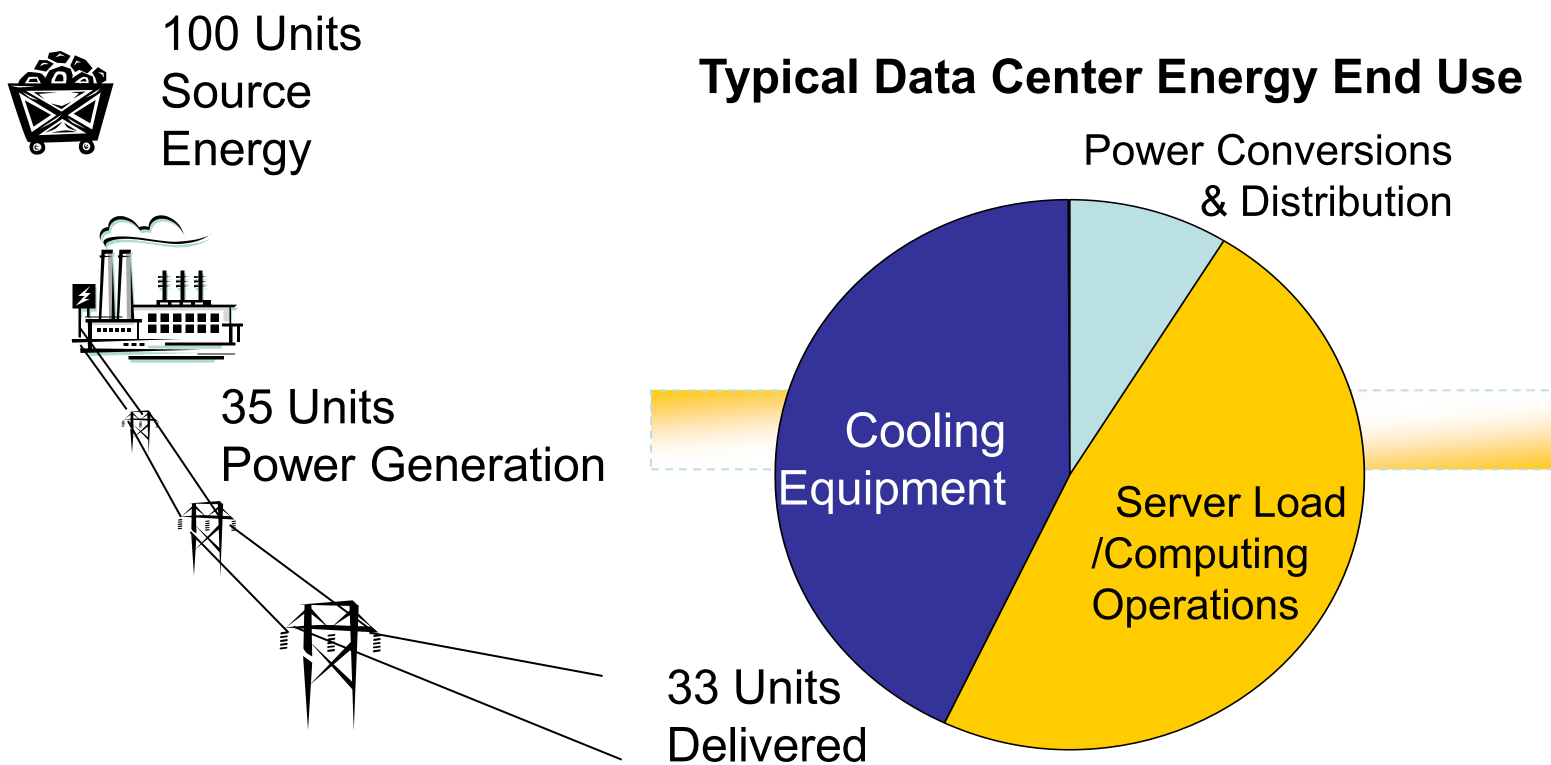
Data center definitions

• Server closet	< 200 sf
• Server room	< 500 sf
• Localized data center	<1,000 sf
• Mid-tier data center	<5,000 sf
• Enterprise class data center	5,000+ sf

Today's training focuses on larger data centers — however most principles apply to any size center

Data center energy efficiency = 15% (or less)

Energy Efficiency = Useful computation / Total Source Energy



Data center efficiency opportunities

Benchmarking over 30 centers consistently lead to opportunities

No silver bullet

Lots of silver bb's

Many areas for improvement…

Cooling

- Air Management
- Free Cooling – air or water
- Environmental conditions
- Centralized Air Handlers
- Low Pressure Drop Systems
- Fan Efficiency
- Cooling Plant Optimization
- Direct Liquid Cooling
- Right sizing/redundancy
- Heat recovery
- Building envelope

Electrical

- UPS and transformer efficiency
- High voltage distribution
- Premium efficiency motors
- Use of DC power
- Standby generation
- Right sizing/redundancy
- Lighting – efficiency and controls
- On-site generation

IT

- Power supply efficiency
- Standby/sleep power modes
- IT equipment fans
- Virtualization
- Load shifting
- Storage de-duplication

Some strategies could be demand response strategies

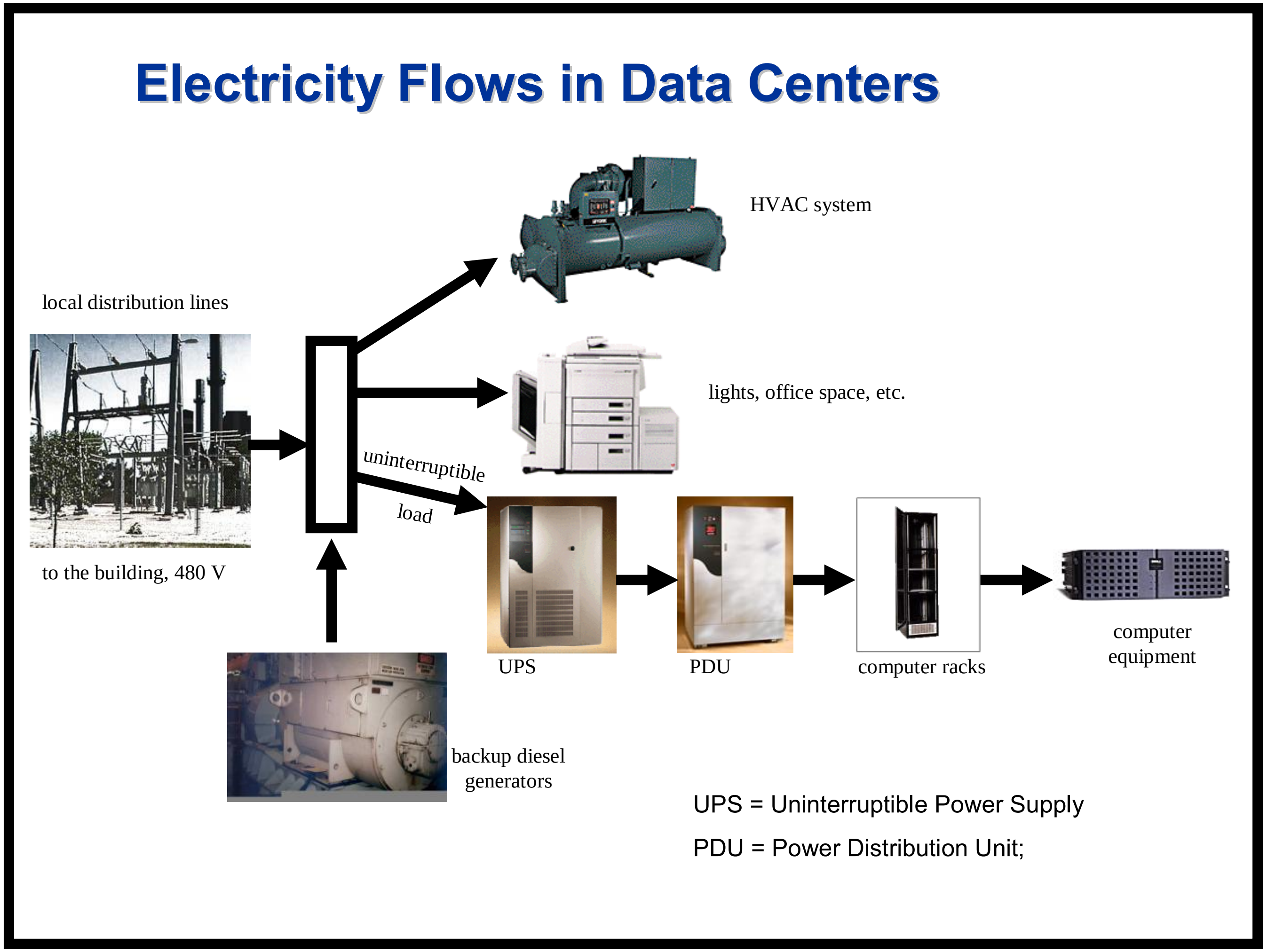
But what are the potential savings?

- 20-40% savings are typically possible
- Aggressive strategies – better than 50% savings
- Paybacks are short – 1 to 3 years are common
- Potential to extend life and capacity of existing data center infrastructure but this also could allow for more IT equip – raising total energy use
- Most don’t know if their center is good or bad

Potential savings

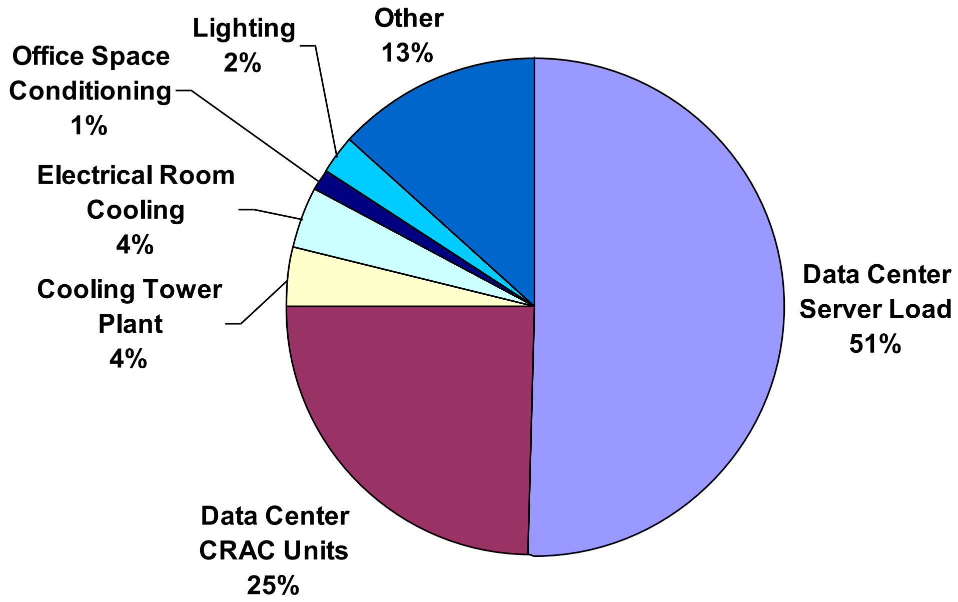
- 20-40% savings are typically possible
- Aggressive strategies – better than 50% savings
- Paybacks are short – 1 to 3 years are common
- Potential to extend life and capacity of existing data center infrastructure
- Some opportunities need to be integrated with infrastructure upgrades
- Most centers don’t know if they are good or bad

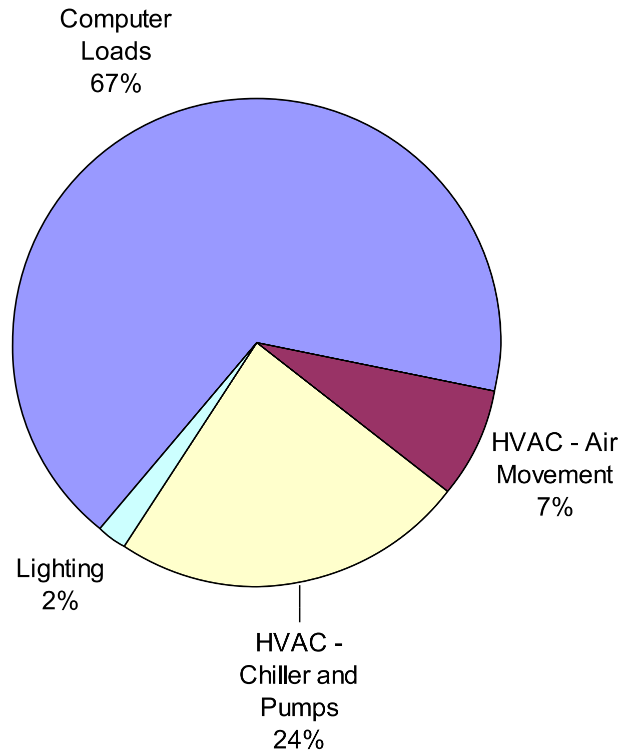
Benchmarking energy end use



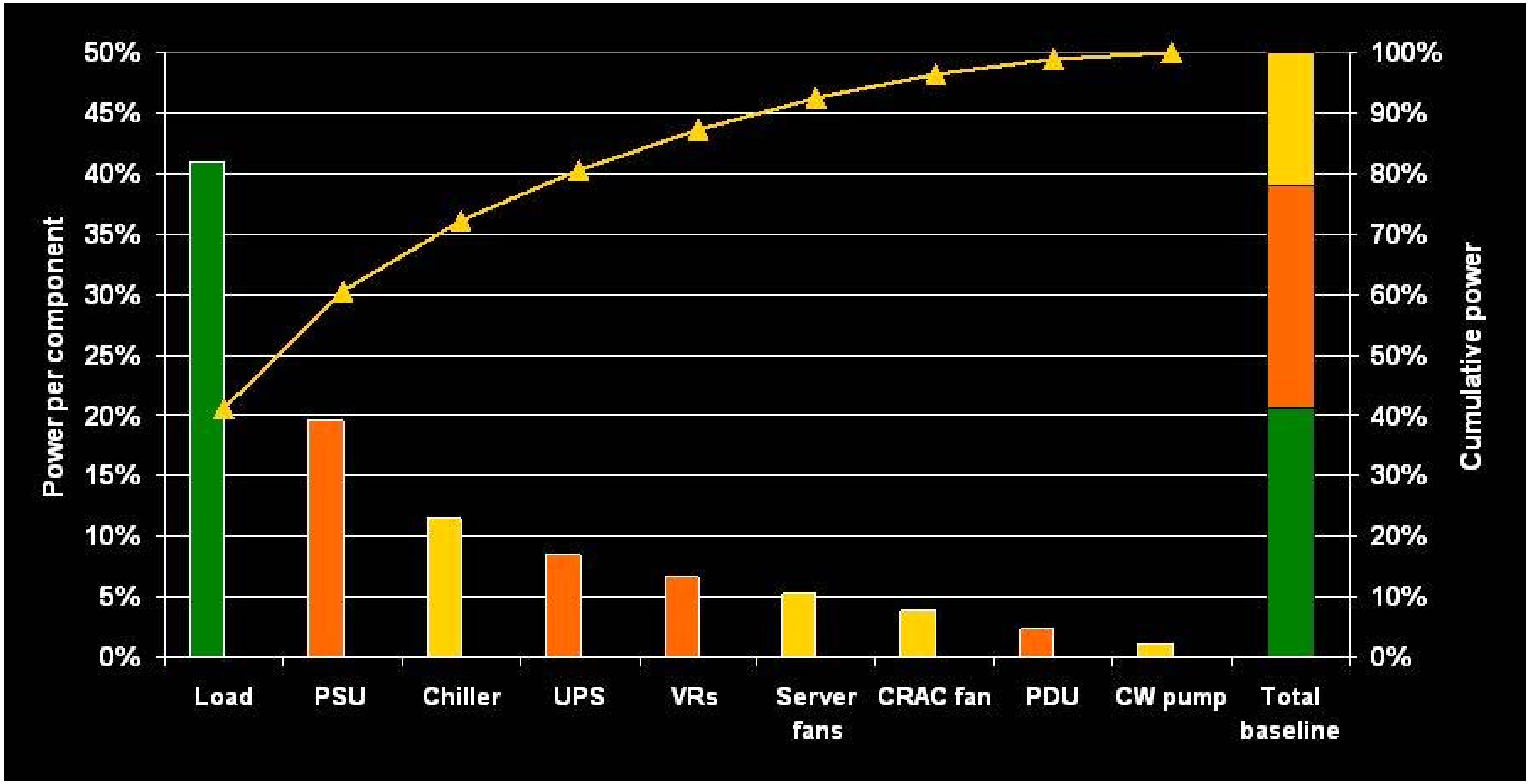
Your mileage will vary

The relative percentages of the energy doing computing varied considerably.





Electrical end use in one center



Courtesy of Michael Patterson, Intel Corporation

Data center cooling and power conversion performance varies

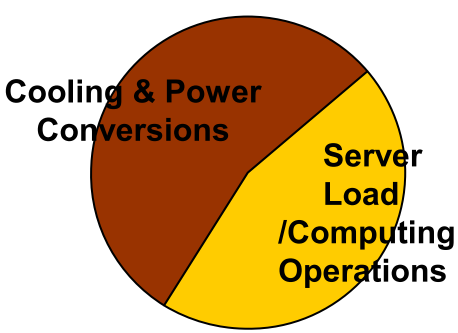
DCiE (Data Center Infrastructure Efficiency) ~ 0.5

- Power and cooling systems are not optimized
- Currently, power conversion and cooling systems consume half or more of the electricity used in a data center: *Less than half of the power is for the servers*

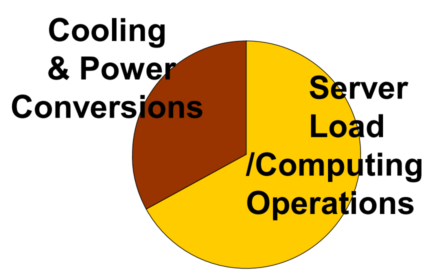
DCiE

Data Center Infrastructure Efficiency

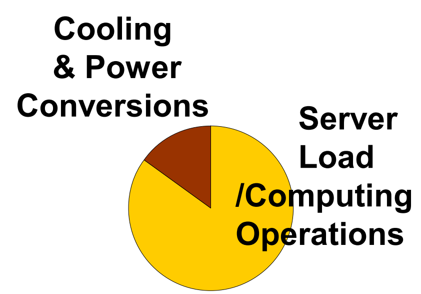
$$\text{DCiE} = \frac{\text{Energy for IT Equipment}}{\text{Total Energy for Data Center}}$$



Typical Practice
DCiE < 0.5

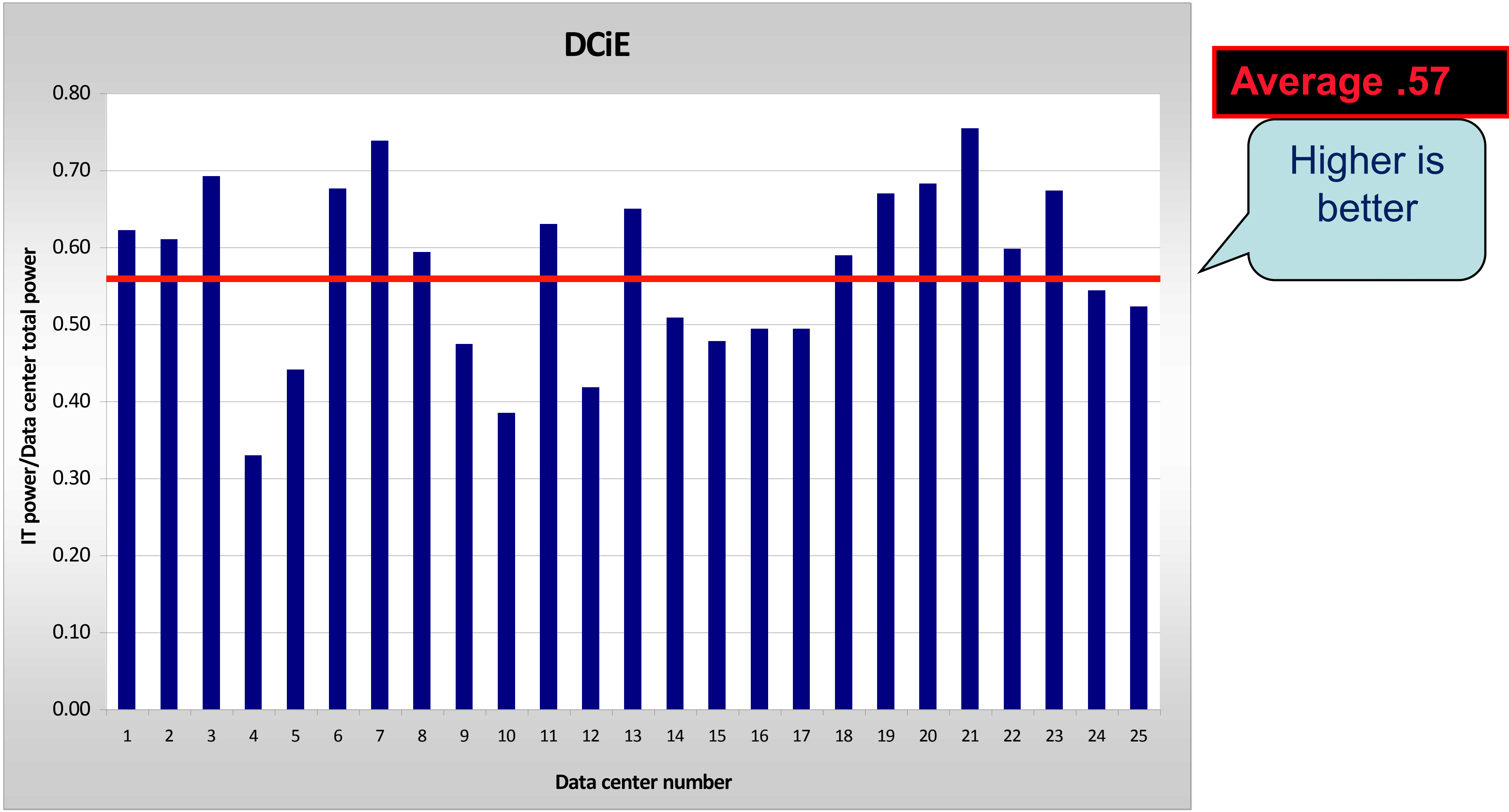


Better Practice
DCiE = 0.7



Best Practice
DCiE = 0.85

High level metric: DCiE = IT/total

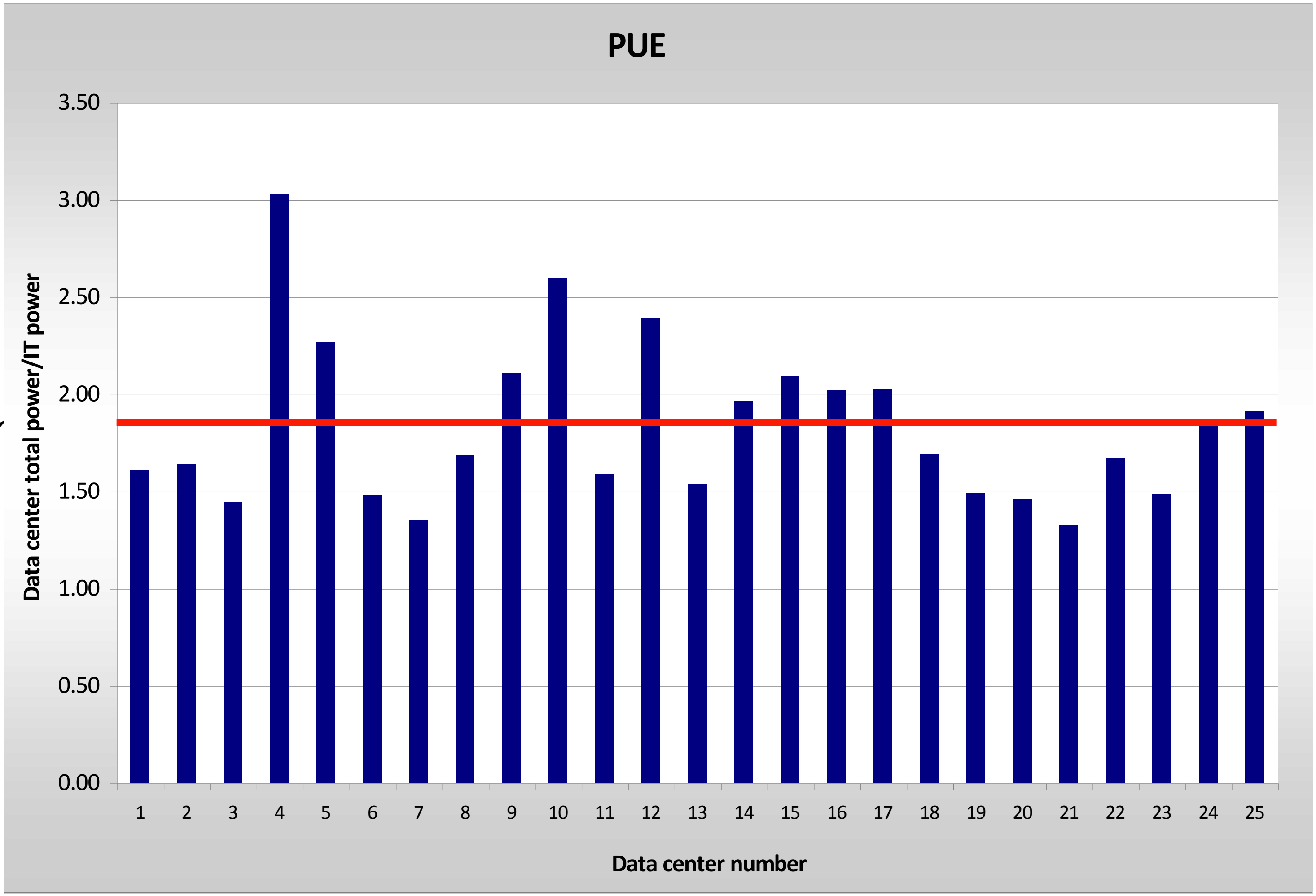


Source: LBNL

Inverse metric: PUE = total/IT

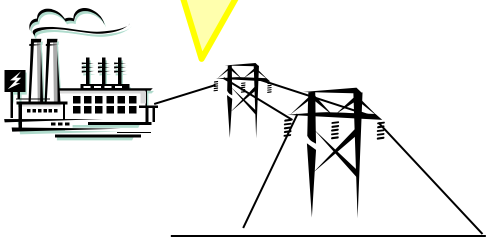
Average 1.83

Lower is better



Efficiency opportunities are everywhere

Source and transmission losses



- Load management
- Virtualization
- Server innovation
- Heat recovery

- Better air management
- Better environmental conditions
- Move to liquid cooling
- Optimized chilled-water plants
- Use of free cooling

Power Conversion & Distribution

Server Load/ Computing Operations

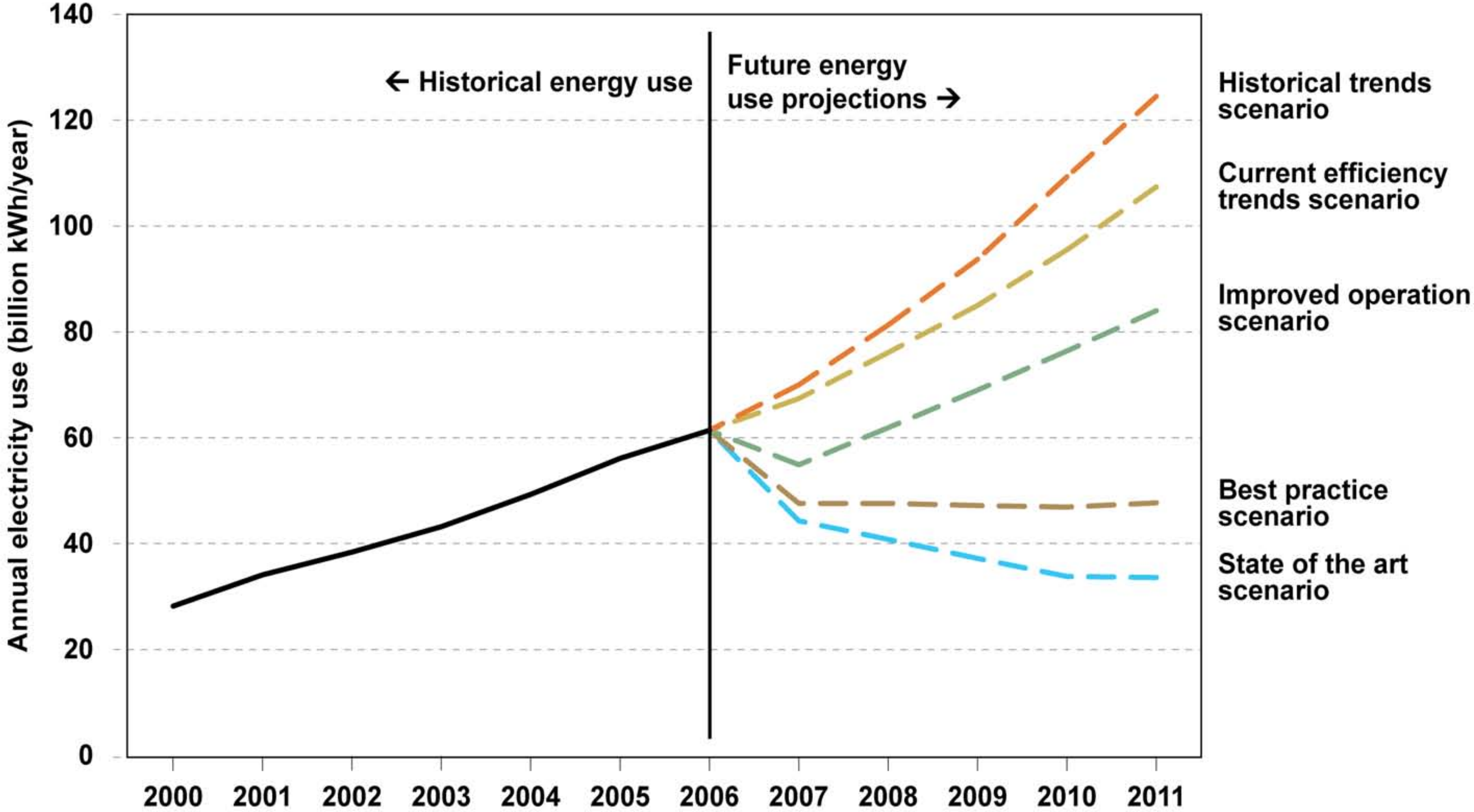
Cooling Equipment

On-site generation

- High voltage distribution
- Use of DC power
- Highly efficient UPS systems
- Efficient redundancy strategies

- Rejected heat for cooling
- Use of renewable energy/fuel cells
- Eliminate transmission losses

Scenarios of projected energy use from EPA report to Congress 2007 - 2011

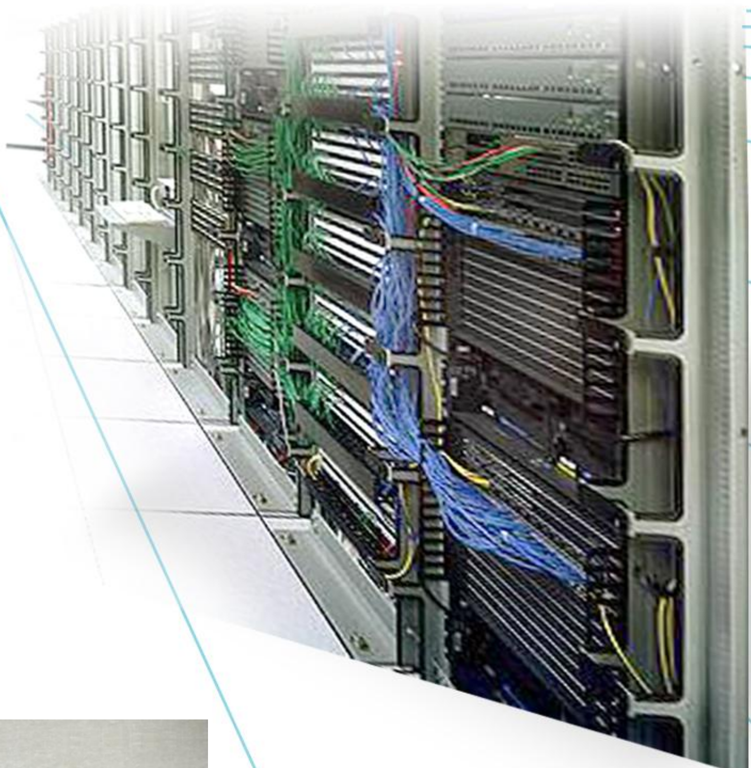


Spotlight on efficiency:

- Industry is taking action
  - IT manufacturers
  - Infrastructure equipment manufacturers
- Industry Associations are active:
  - ASHRAE
  - Green Grid
  - Uptime Institute
  - Afcom
  - Critical Facilities Roundtable
  - 7 X 24 Exchange
- Utilities and governments initiating programs to help

Overview take aways

- Various meanings for “data centers”
- Benchmarking helps identify performance
- Benchmarking suggests best practices
- Efficiency varies
- Large opportunity for savings
- Industry is taking action
- Resources are available



IT Equipment Efficiency

Bill Tschudi, PE

IT equipment load

- Predicting IT loads
  - Over sizing, at least initially, is common
  - Over sizing of IT can lead to inefficiencies in electrical and mechanical system and higher installed system costs
- IT loads can be controlled
  - Server efficiency
    - Power supply efficiency
    - Redundancy options
    - Low power modes
    - Fan energy
    - Liquid cooling
  - Software efficiency (Virtualization, MAID, etc.)
  - Redundancy and back-up power
- Implement modular and scalable approaches
- Reducing IT load has a multiplier effect

The value of one watt saved at the server CPU

1 Watt at CPU

= 1.25 Watts at entry to server (80% efficient power supply)

= 1.56 Watts at entry to UPS (80% efficient power supply)

= 2.5 Watts including cooling (2.0 PUE)

= 22 kWh per year

= $2.20 per year (assuming $0.10/kWh)

= $6 of infrastructure cost (assuming $6/W)

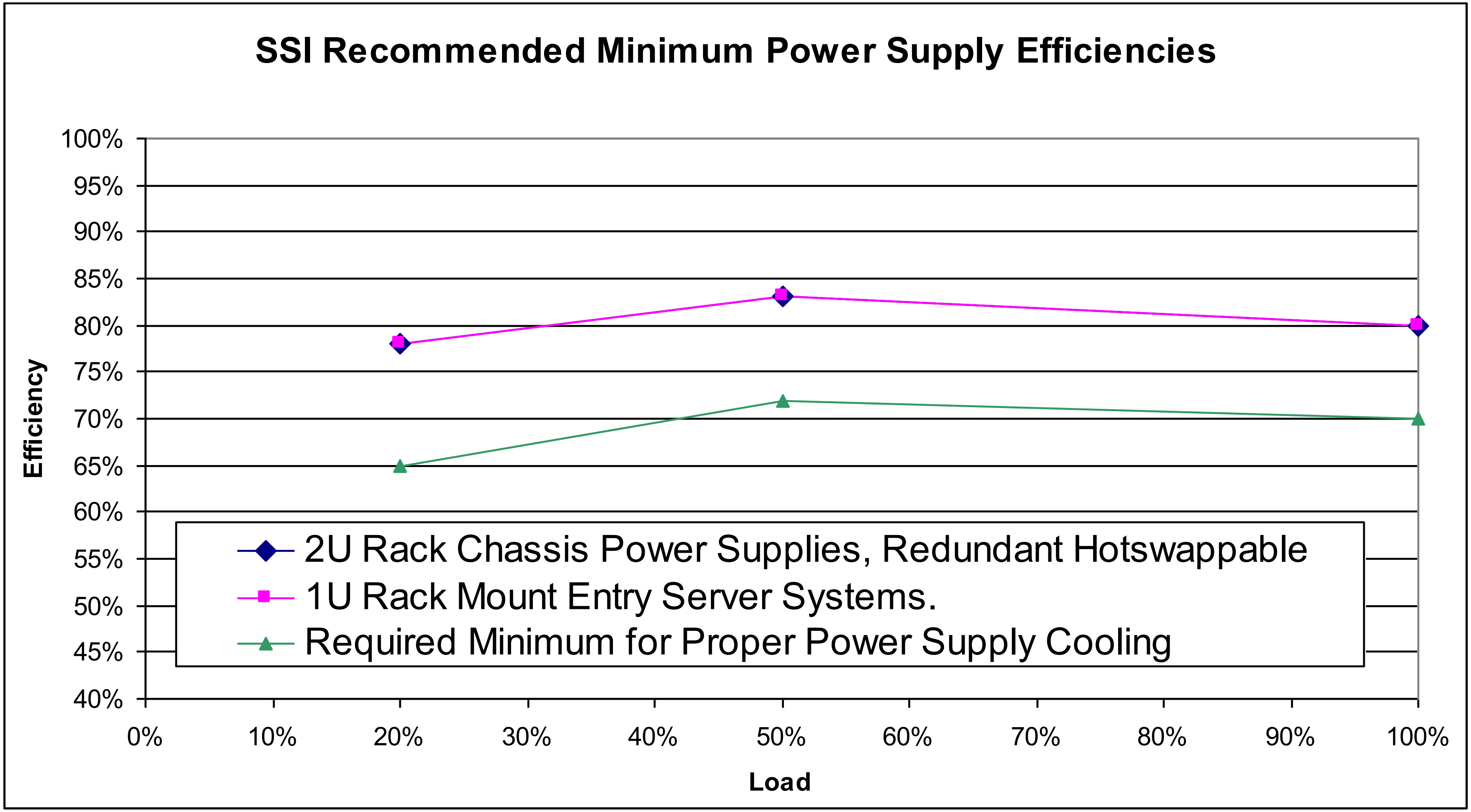
- **Total Cost of Ownership (TCO) Perspective = $12.60 (assuming three year life of server)**
- **Typical added cost of 80 plus power supply $3 - $5.**
- **Typical value - $170 (assumes 15 Watts saved at power supply not CPU)**

$$\text{Energy} \quad \frac{15w \times 2.0PUE \times \$0.10/kw \times 8{,}760hrs/yr}{1{,}000w/kW} \times 3yrs \approx \$80$$

$$\text{Infrastructure } 15\text{w} \times \$6/\text{watt} = \$90$$

$$\text{Total } \$80 + \$90 = \$170$$

Efficient power supplies



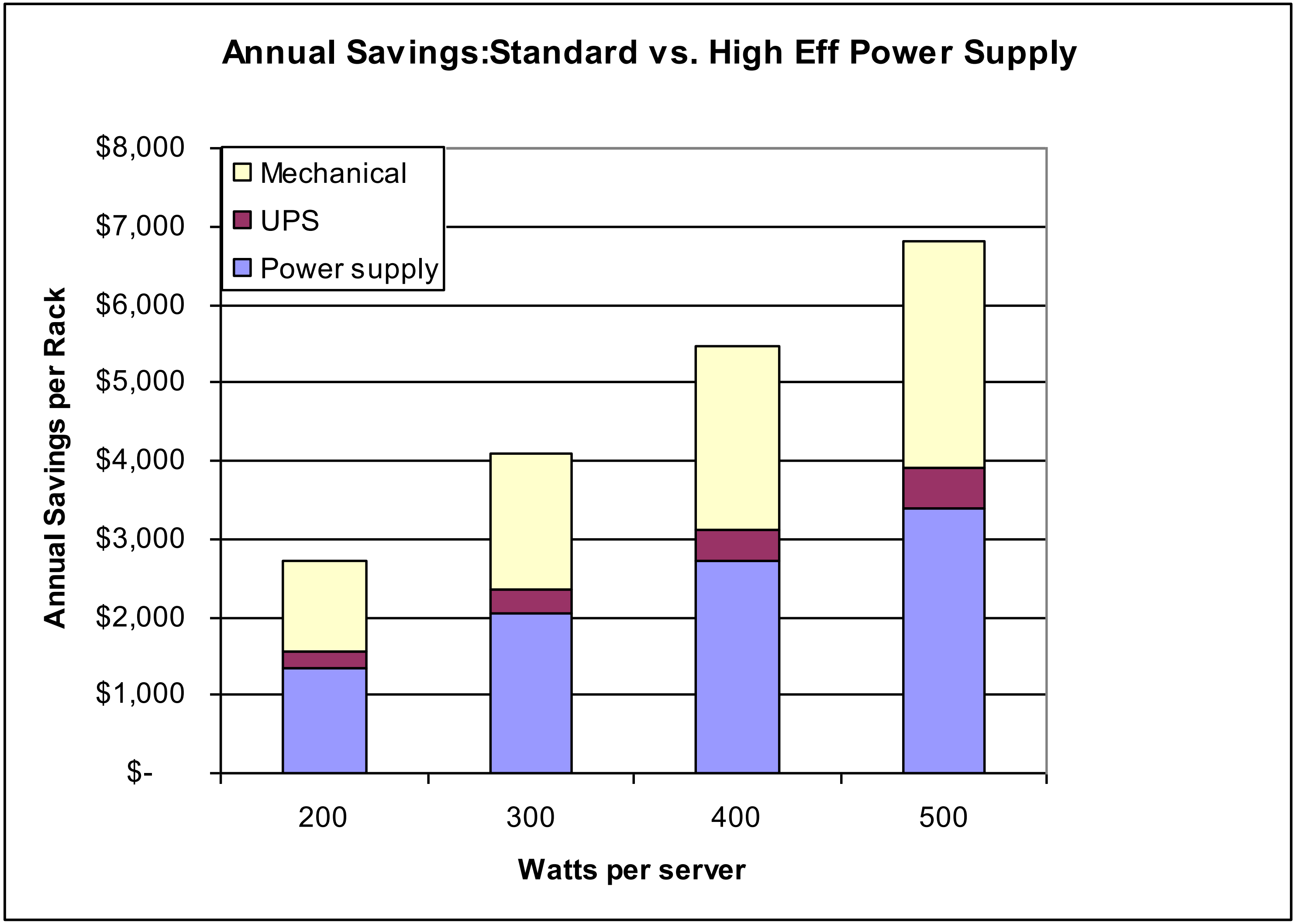
Server System Infrastructure (SSI) Initiative (SSI members include Dell, Intel, and IBM)

Power supply, per server savings

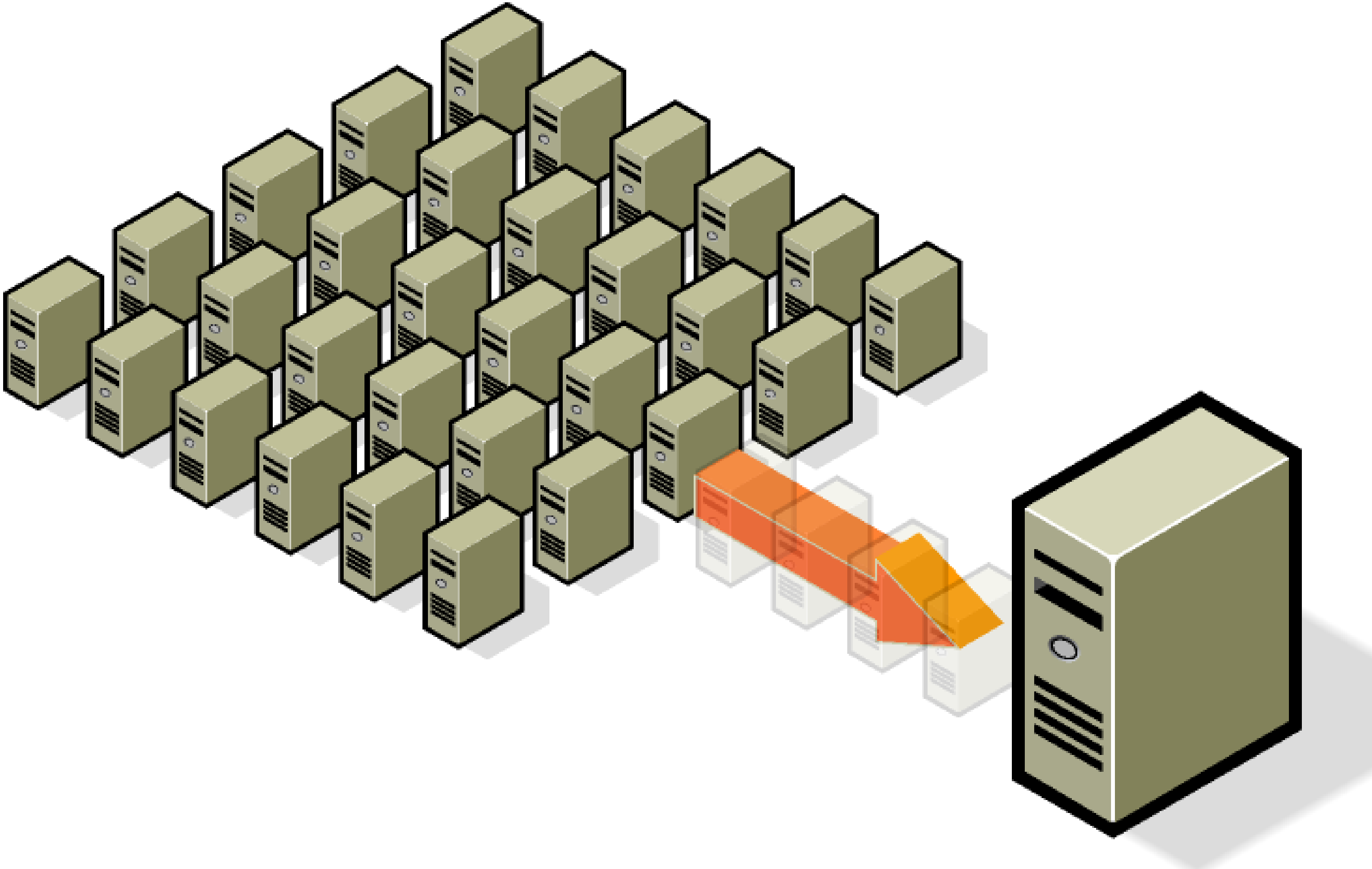
Power Supplied Per Server (Watts)	Annual Savings Using a SSI Recommended Minimum Efficiency Supply[1]	Annual Savings Including Typical Cooling Energy[2]
200	$ 37	$ 65
300	$ 56	$ 97
400	$ 74	$ 130
500	$ 93	$ 162

- 1. Assuming $0.10/kWh, 8760 hr/yr, 85% efficient UPS supply, 72% efficiency baseline PS
- 2. Cooling electrical demand is estimated 75% of rack demand, the average ratio of 12 benchmarked datacenter facilities

Power supply savings add up



Server virtualization



Server virtualization

- Energy savings and potential utility incentive for Server Virtualization.
- Number of servers before virtualization: 50.
- Number of servers after virtualization: 30.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Total Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install Virtual Server - Direct Energy Savings	98,550	59,130	39,420	$ 4,730	$ 3,154	$ 70,000
Install Virtual Server - Indirect Equipment Support Savings	60,636	36,382	24,254	$ 2,911	$ -	$ -
Combined	159,186	95,512	63,674	$ 7,641	$ 3,154	$ 70,000

Thin clients

- Typical Desktop Computer, 75 – 100 Watts, $500
- Typical Laptop Computer, 10 – 15 Watts, $1,000
- Typical Thin Client, 4 – 6 Watts, $300

Thin clients

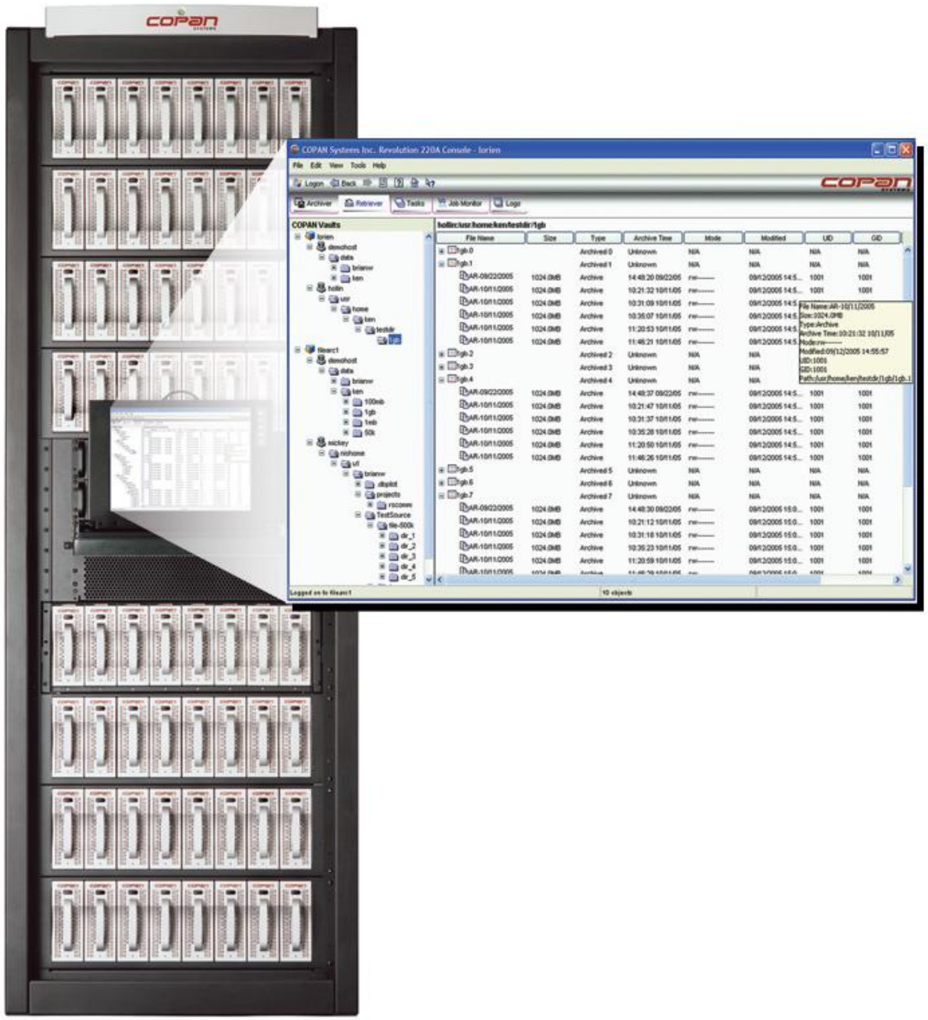
- Energy savings and utility incentive for implementation of a Thin Client network.
- Replace 50 generic workstations with 50 Thin Client terminals.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Total Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install Thin Client Computers - Direct Energy Savings	35,040	15,626	19,414	$ 2,330	$ 1,553	$ 25,000
Install Virtual Server - Indirect HVAC Savings	12,856	5,733	7,123	$ 855	$ -	$ -
Combined	47,896	21,359	26,537	$ 3,184	$ 1,553	$ 25,000

Massive array of idle disks (MAID)

- MAID is designed for Write Once, Read Occasionally (WORO) applications.

- In a MAID each drive is only spun up on demand as needed to access the data stored on that drive.



Massive array of idle disks (MAID)

- Energy savings and possibly utility incentive for installation of a MAID system.
- Install one fully-loaded MAID cabinet with a total storage capacity of 448TB in lieu of a traditional cabinet of the same capacity.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Incremental Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install Maid System - Direct Energy Savings	278,450	75,118	203,332	$ 26,551	$ 16,267	$ 224,000
Install Maid System - Indirect HVAC Savings	102,163	27,561	74,602	$ 9,742	$ 10,444	$ -
Combined	380,613	102,679	277,934	$ 36,293	$ 26,711	$ 224,000

IT take aways

- Efficient power supplies have large annual savings
- Efficient IT equipment reduces infrastructure power consumption
- Efficient servers are orders of magnitude more efficient than older equipment
- Utility incentives may be available
- Virtualization can eliminate many servers
- Thin clients are economical and great energy savers
- Software to limit spinning discs has large promise
- Saving one watt at the server saves 2.5 watts overall

Electrical Systems Efficiency

Bill Tschudi, PE

Electrical Systems Efficiency

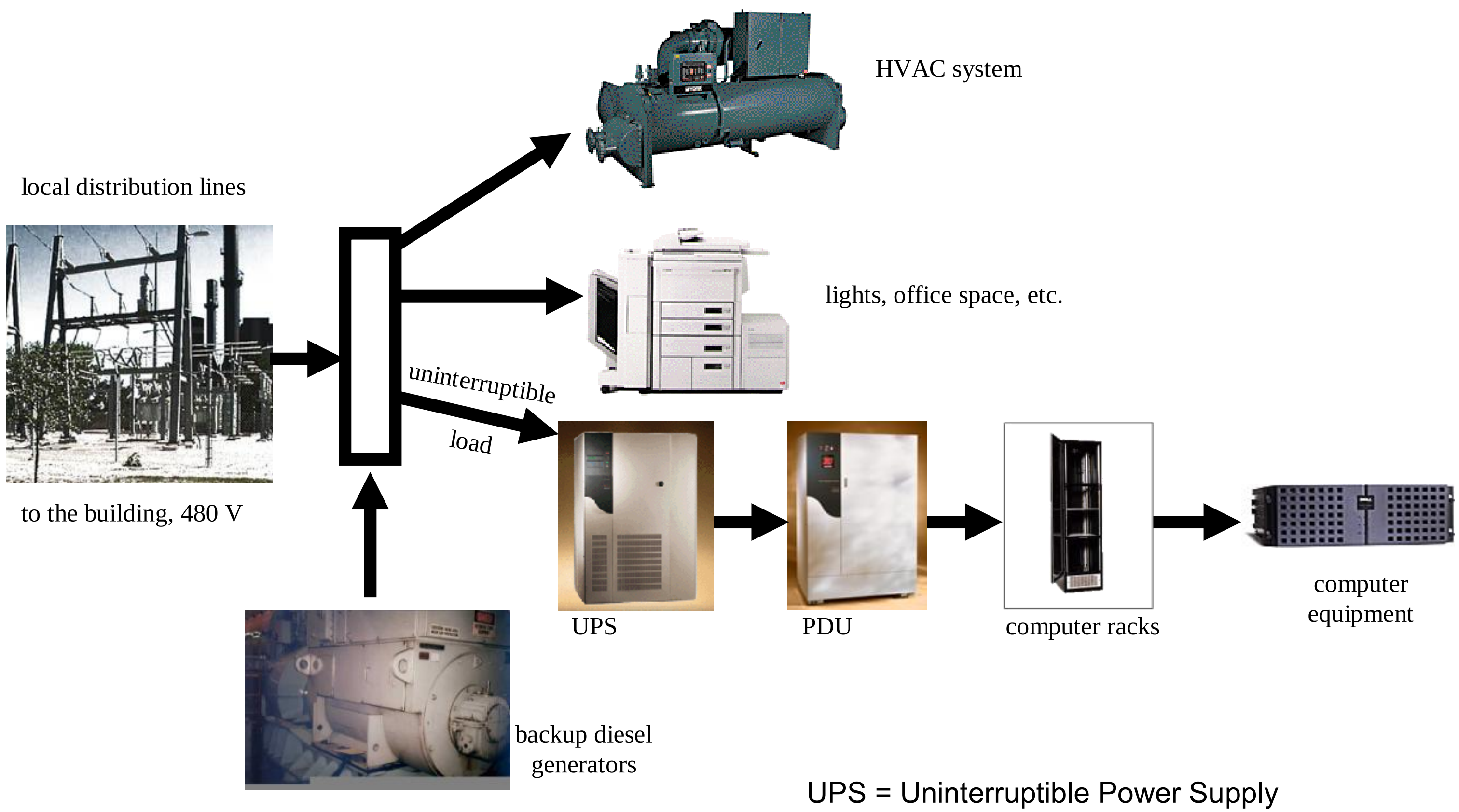
Focus Areas:

- Electrical distribution systems
- Motor efficiency
- Lighting
- Standby generation
- On-site generation

Electrical System Efficiency Issues

- Infrastructure is typically oversized for much of its life because power requirements are overstated
- Legacy equipment is inefficient
- IT equipment is on and not doing anything
- Multiple power conversions – some power is converted to heat which must then be removed
    - UPS
    - Transformers and PDUs (with transformers)
- Lighting efficiency and lighting controls
- Distribution voltages are not optimized
- Standby generator block heaters not optimized

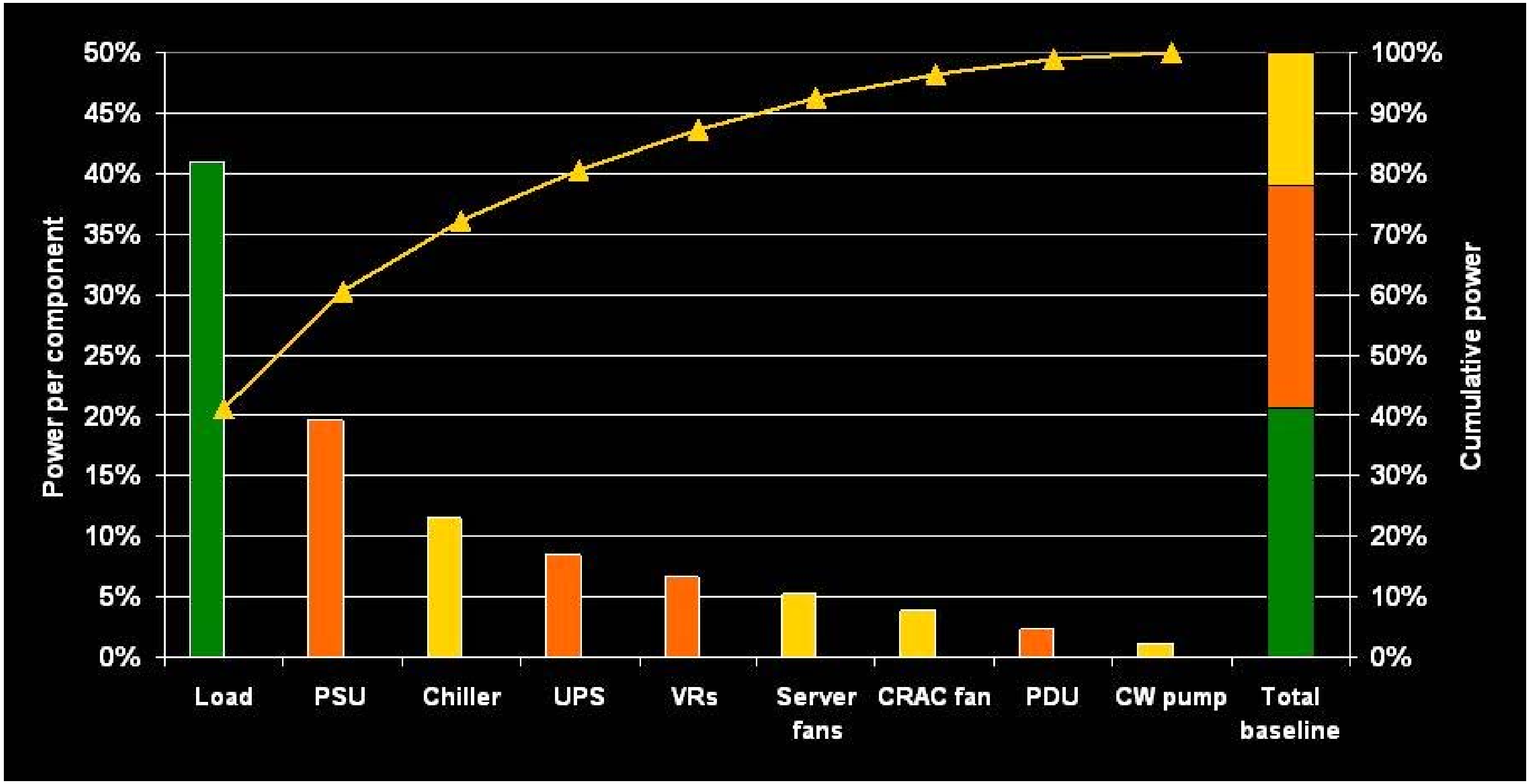
Electricity Flows in Data Centers



UPS = Uninterruptible Power Supply

PDU = Power Distribution Unit;

Overall power use in data centers

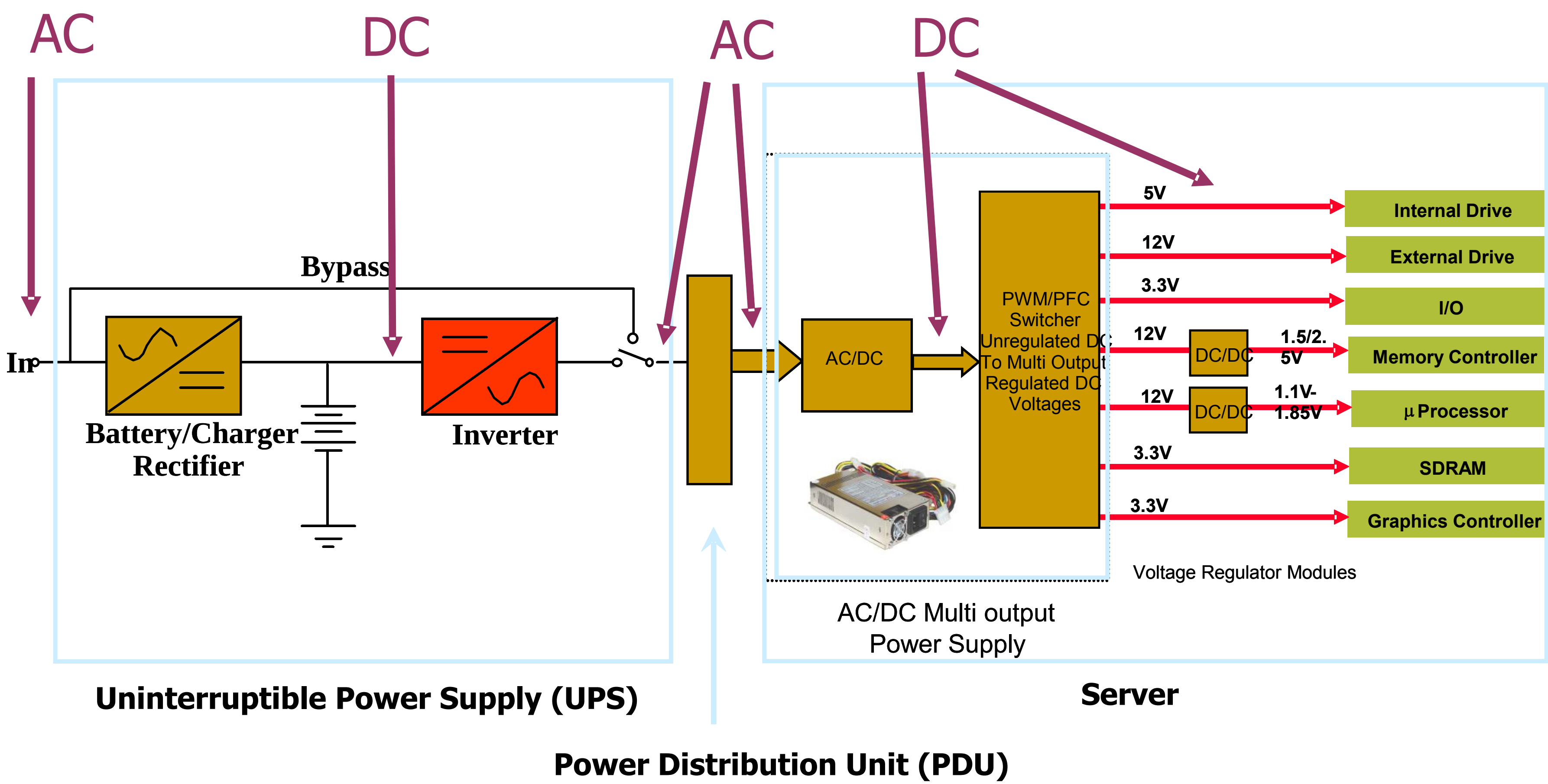


Courtesy of Michael Patterson, Intel Corporation

Electrical Distribution 101

- Every power conversion (AC-DC, DC-AC, AC-AC) loses some energy and creates heat
- Efficiency decreases when systems are lightly loaded
- Distributing higher voltage is more efficient and saves capital cost (conductor size is smaller)
- Uninterruptible power supply (UPS), transformer, and PDU efficiency varies
- Efficiency of power supplies in IT equipment varies

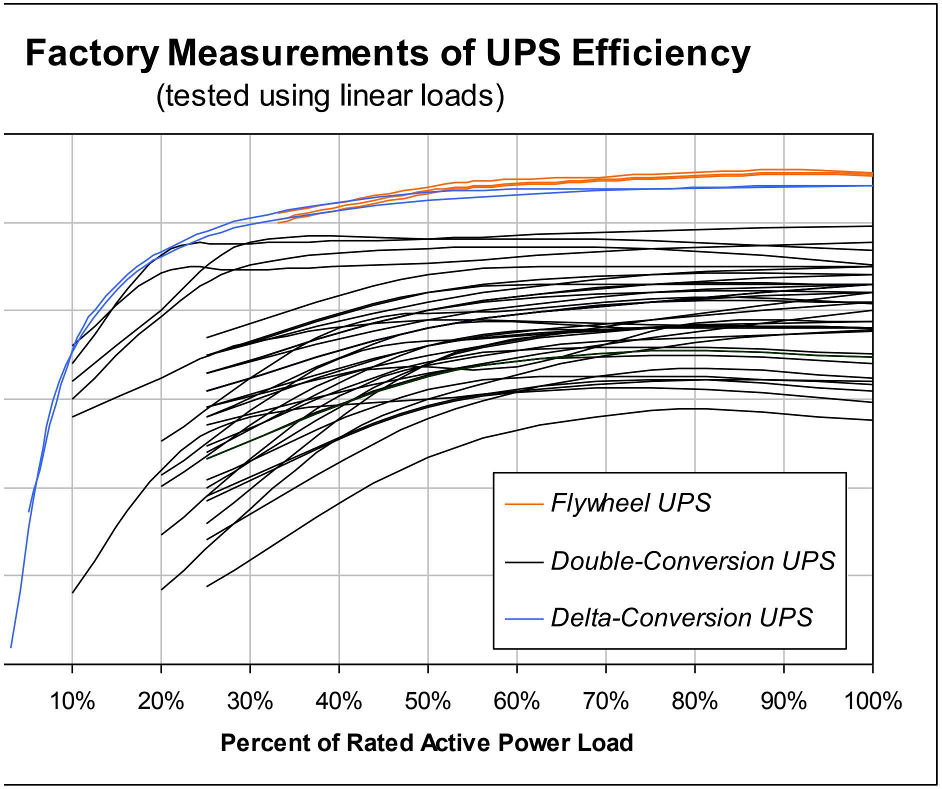
From utility power to the chip -multiple electrical power conversions



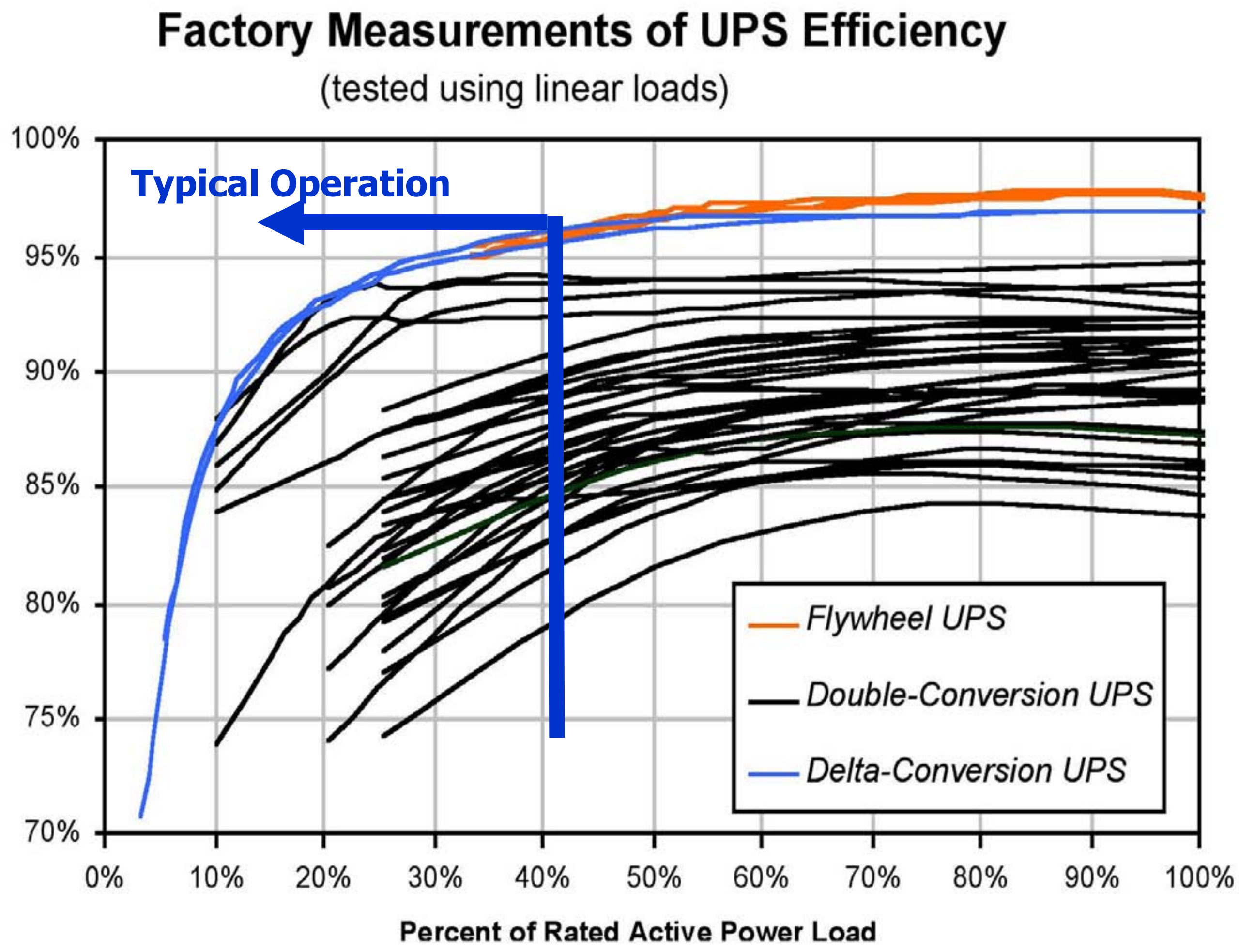
UPS systems, transformers, and PDUs efficiency

- Efficiencies vary with system design, equipment, and load

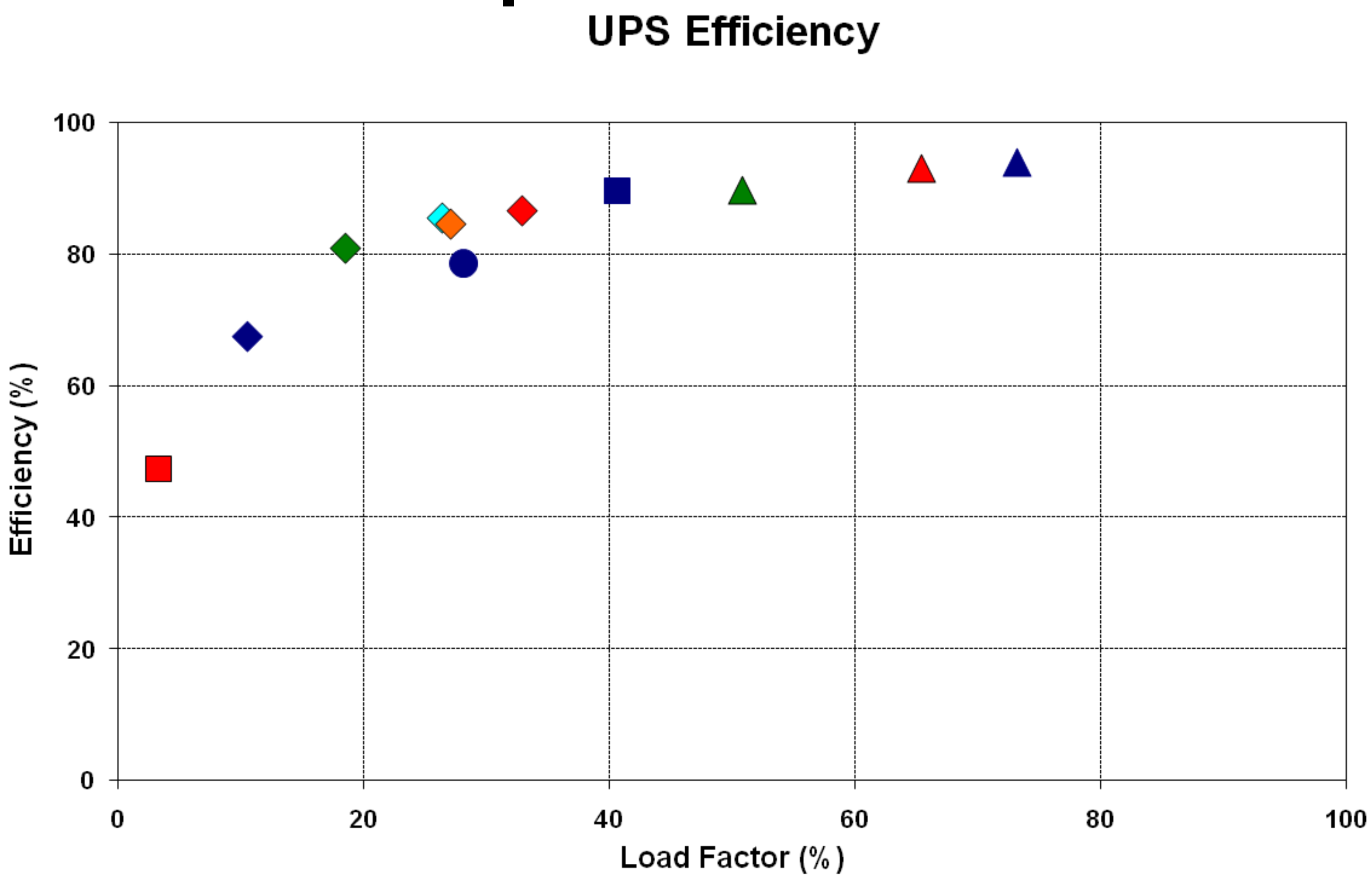
- Redundancies will always impact efficiency



UPS factory measurements

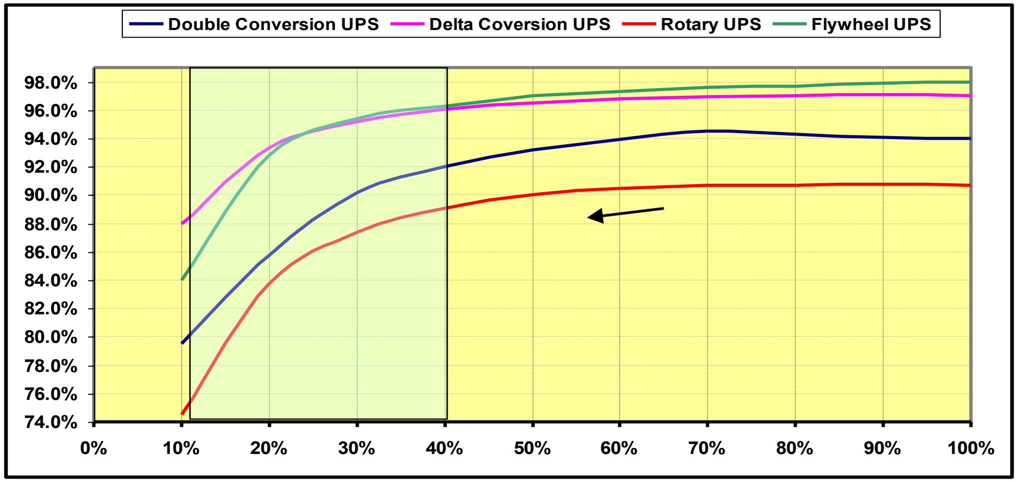


Measured UPS performance



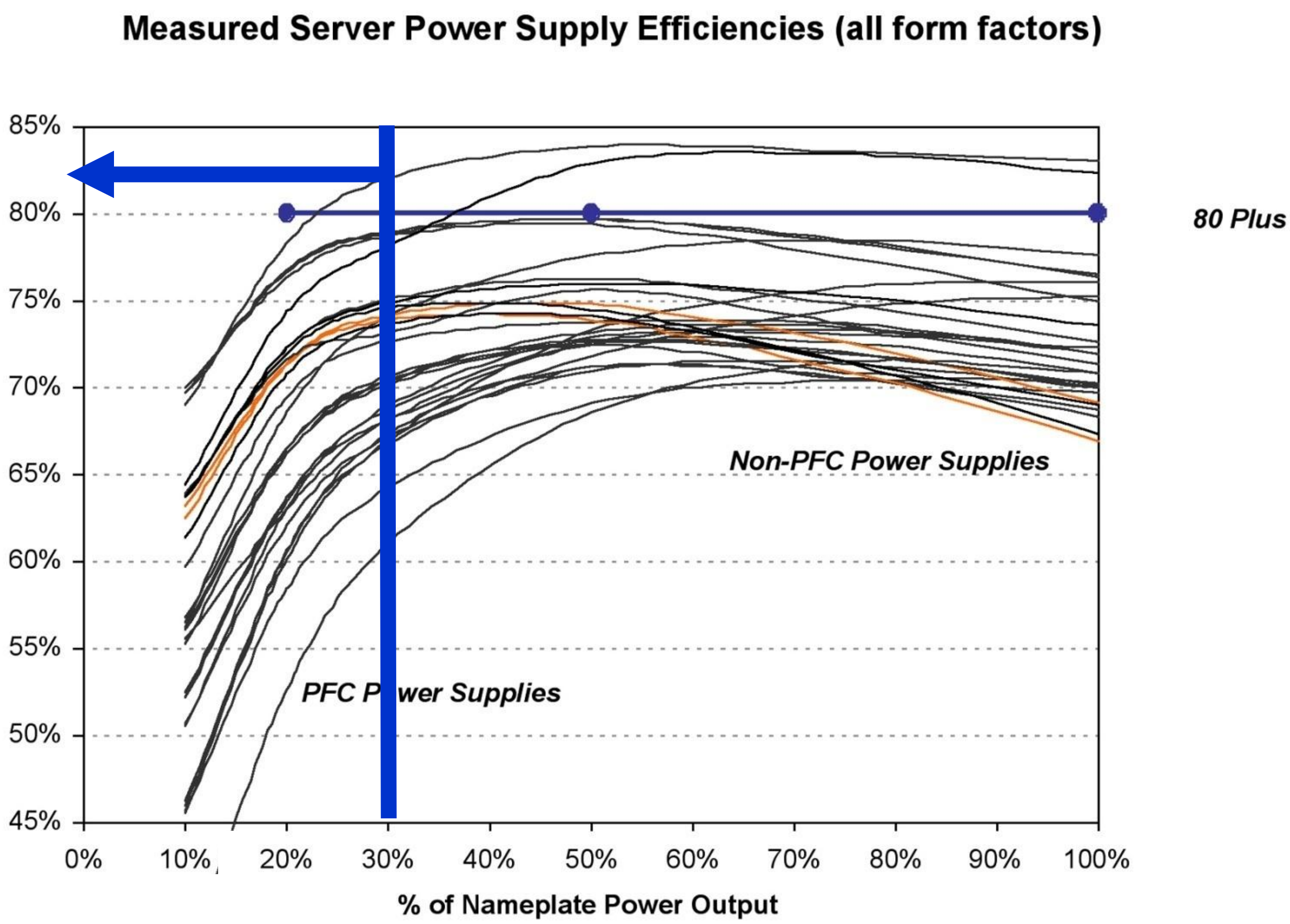
Managing UPS load capacity

Example: **10% difference in UPS efficiency per 1000 kW IT load results in approximately 900 MWhr of Energy saving per year and approx $400K of energy saving over 5 years.**



Most UPS units in N or N+X configuration operate at 10% to 40% load capacity

Measured power supply efficiency



Redundancy

- Understand what redundancy costs and what it gets you – is it worth it?
- Different strategies have different energy penalties (e.g. 2N vs. N+1)
- It's possible to more fully load UPS systems and achieve desired redundancy
- Redundancy in electrical distribution always puts you down the efficiency curve
- Consider other options

Electrical systems sizing

- IT Design Load typically was historically based on IT Nameplate plus future growth

  Problem - actual IT loads are <25% of nameplate

- IT load was determined on a Watts/sf basis

  Problem -IT loads are now concentrated

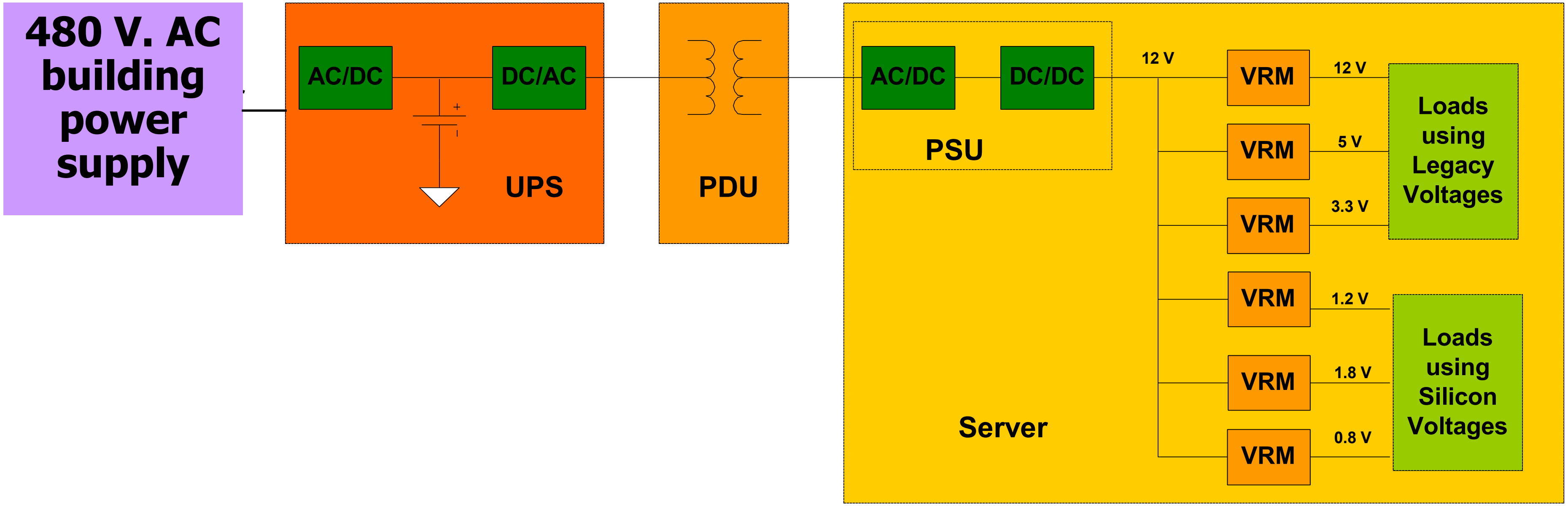
- UPS systems are sized for IT load plus 20-50%

  Problem - load was already oversized by factor of 4

- Standby generators are sized for UPS load x2 or more

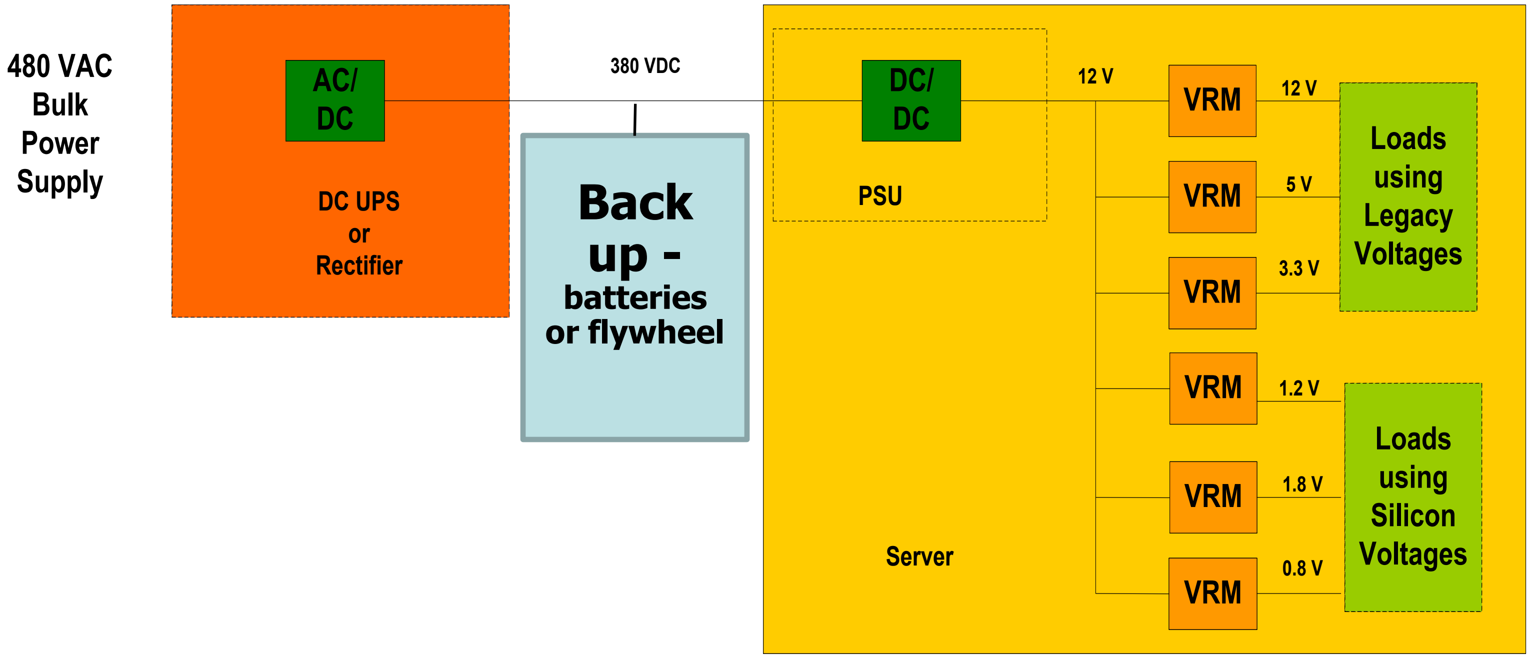
  Problem - block heaters

“Today’s” AC distribution



"400V" DC power distribution

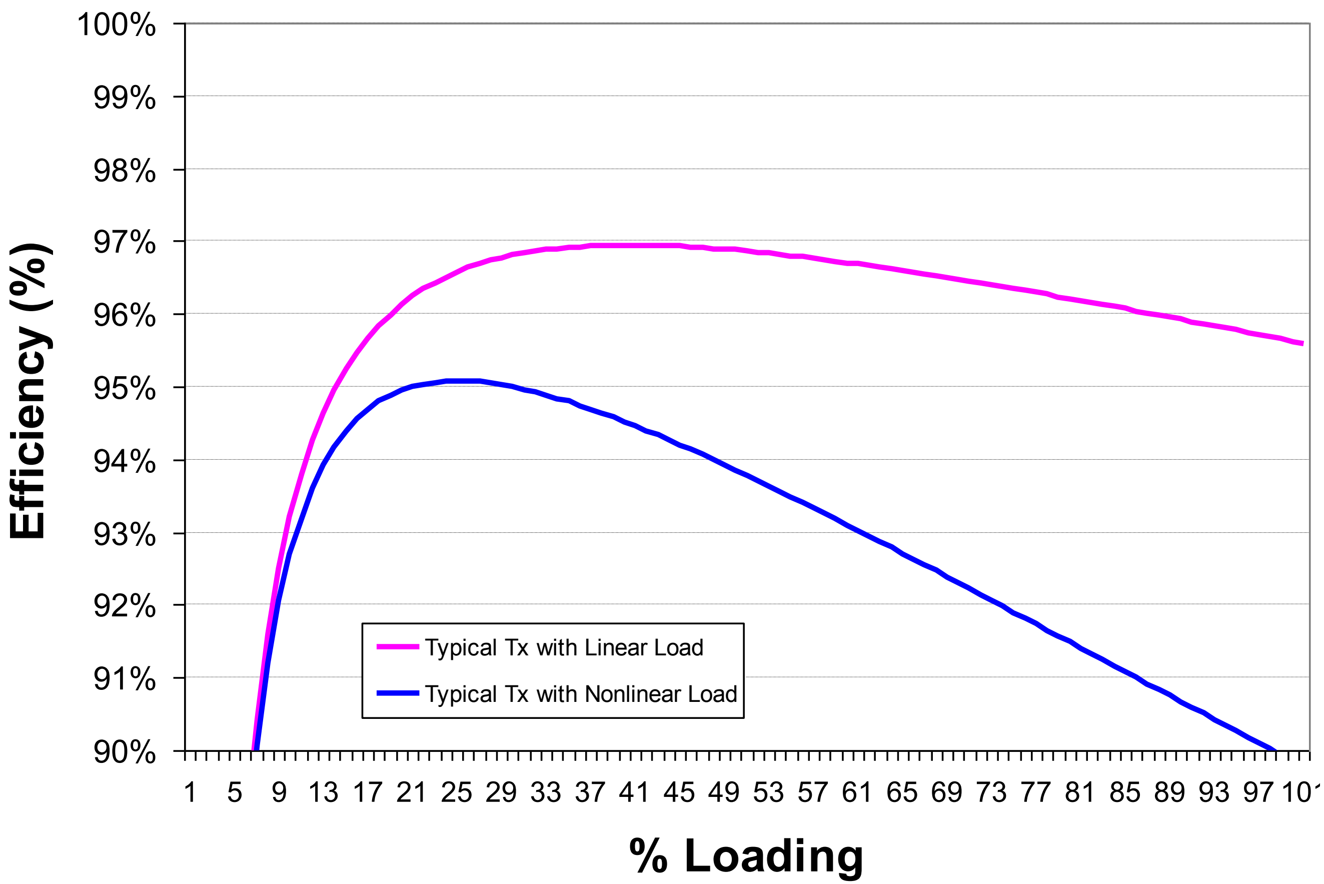
Distributing DC power can eliminate several stages of power conversion and could be used for lighting and variable speed drives.



Transformers and PDUs

- Specify high efficiency transformers at their operating load
- Install low voltage (LV) transformers outside the raised floor area
- More fully load PDUs (with built-in transformers) inside the data center

Typical 112.5kVA nonlinear UL listed transformer



Significant variation in efficiency over load range

Courtesy of PowerSmiths

Data center lighting

- Lights are on and nobody’s home
  - Switch off lights in unused/unoccupied areas or rooms (UPS, Battery, S/Gear, etc)
  - Lighting controls such as occupancy sensors are well proven

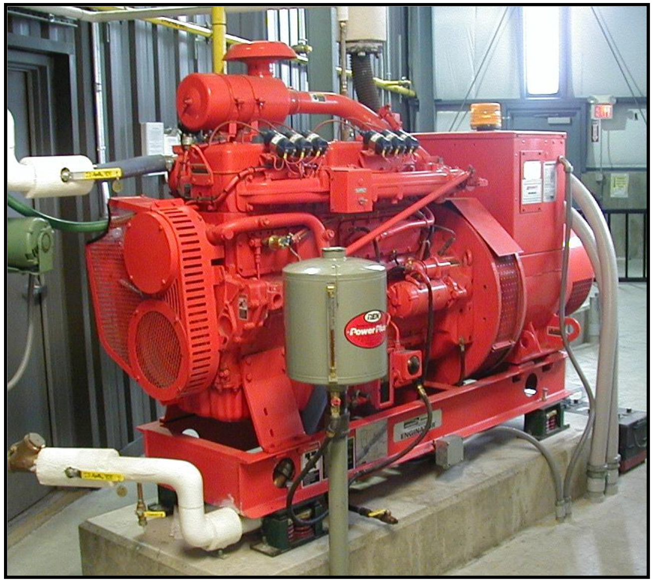
- Small relative benefit but easy to accomplish – also saves HVAC energy

- Use energy efficient lights -Replace older coil/core Ballasts type with new efficient electronic ones

- Lights should be located over the aisles

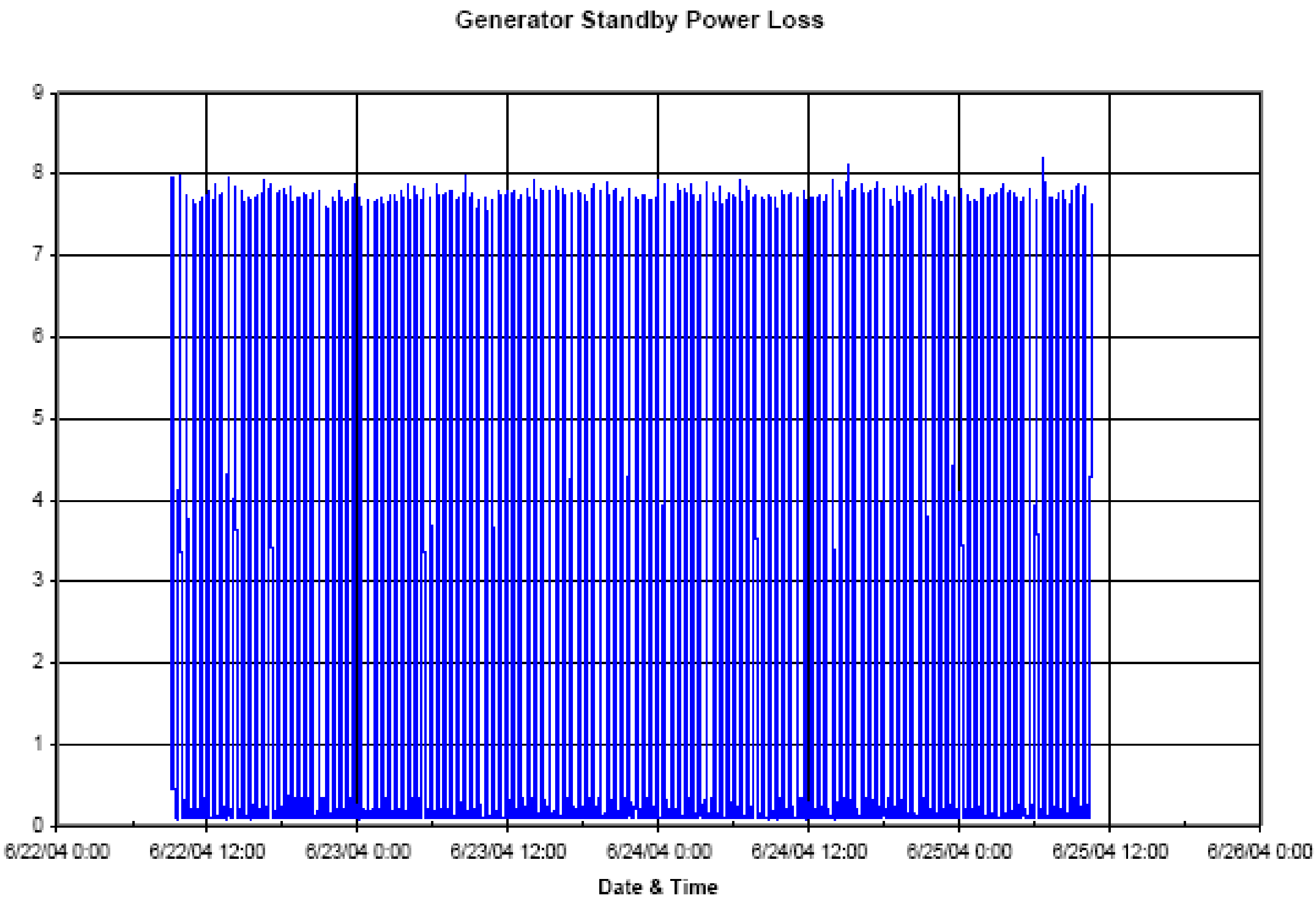
- DC lighting would compliment DC distribution

Standby generation loss



- Several load sources
  - Heaters
  - Battery chargers
  - Transfer switches
  - Fuel management systems
- Opportunity may be to reduce or eliminate heating, batteries, and chargers
- Heaters (many operating hours) use more electricity than the generator will ever produce (few operating hours)
  - Check with the emergency generator manufacturer on how to reduce the overall energy consumption of block heaters i.e. temperature control
- Right-sizing of stand-by generation
- Maintain N+1 redundancy

Standby generator heater



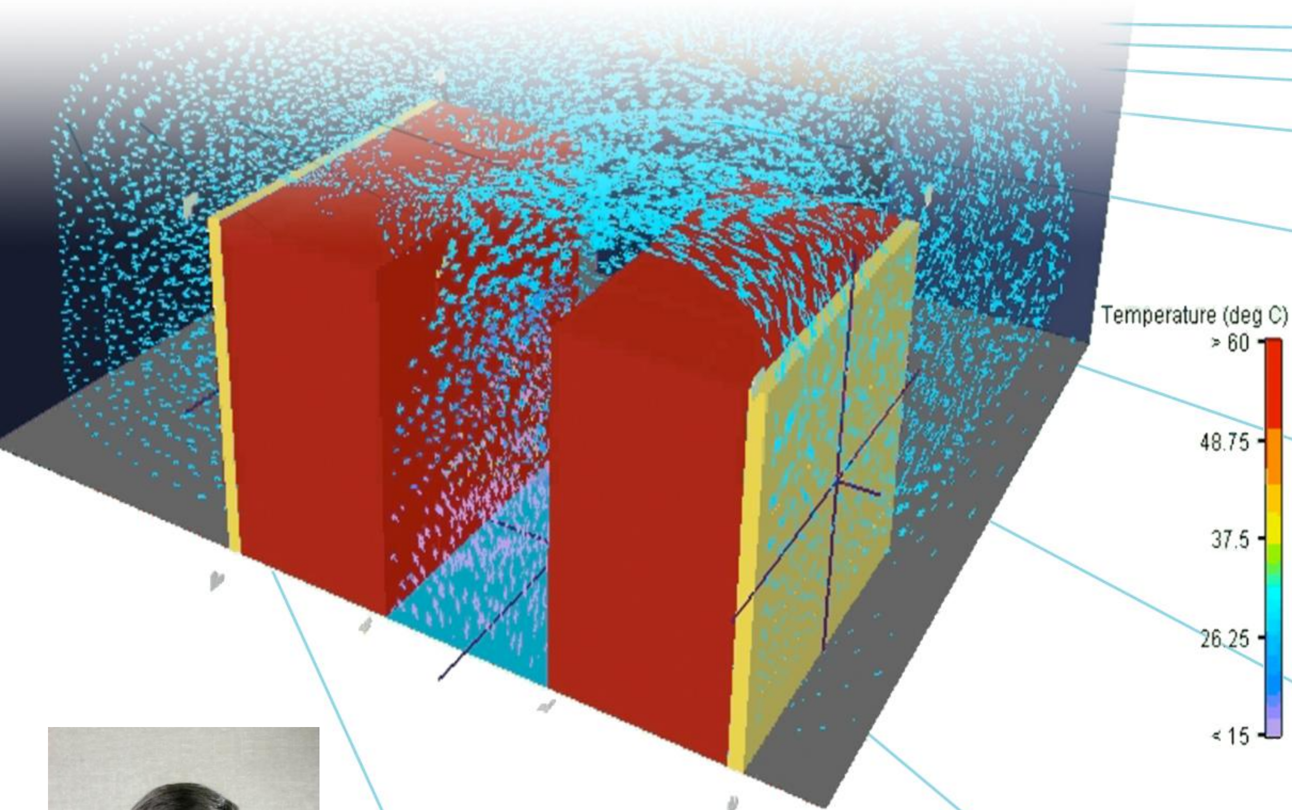
On-site (distributed) generation

- Swap role with Utility for back-up
  - Diesel or Gas- Fired Generators
  - Gas Turbines
  - Micro-Turbines
  - Fuel Cells
  - Bio-Mass
  - Solar
  - Wind
- Can use power plant waste heat
  - For cooling using absorption or adsorption chillers
  - Or other near by use (e.g. campus, laundry, swimming pool, etc.)
- Renewable sources (for dedicated loads such as generator engine block heaters, lights, etc.)

Electrical module take aways

- Distributing higher voltage (AC or DC) is more efficient
- Electrical power conversions lose power creating heat
- Highly efficient UPS's, transformers, PDUs and power supplies should be specified for the loads they will see
- Direct Current (DC) systems can reduce conversion losses
- Redundancy choices affect efficiency in electrical equipment
- Lighting is a small opportunity but easy to implement
- Standby generation losses can be reduced
- On-site generation can improve reliability and efficiency

Break

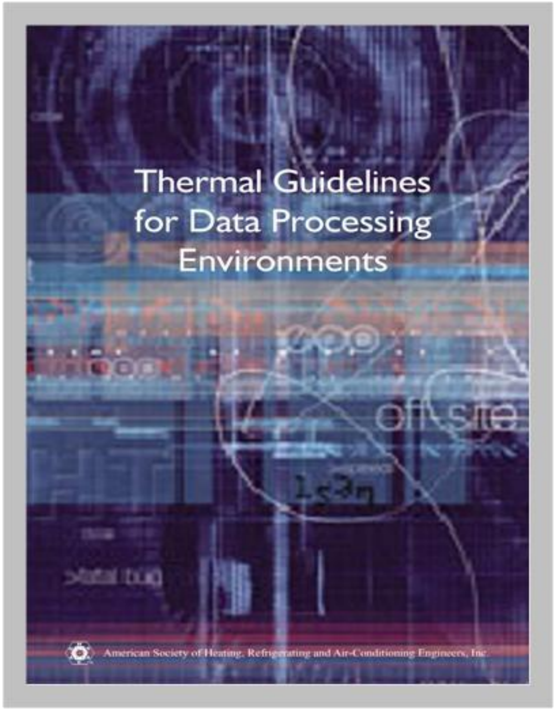


Environmental Conditions

Bill Tschudi, PE

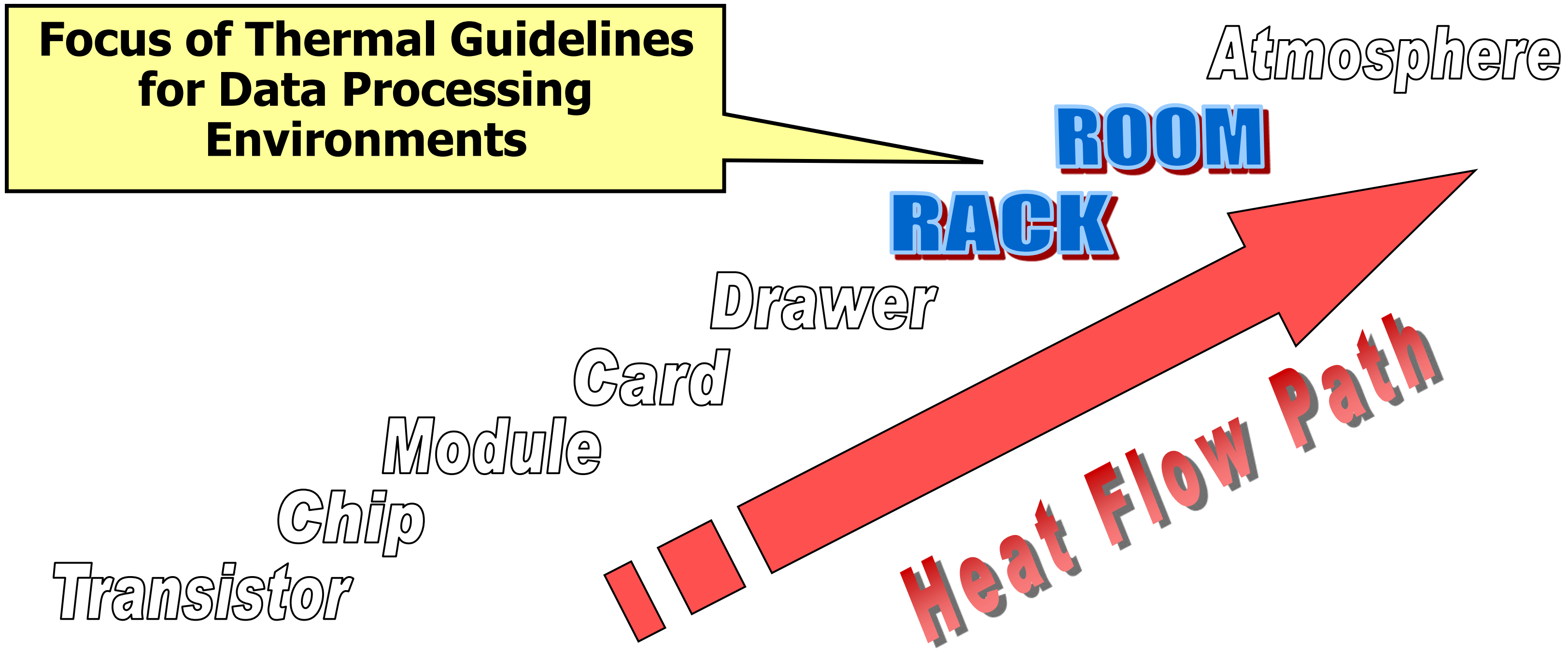
Environmental Conditions

- Most centers are over cooled and have humidity control issues
- ASHRAE and IT equipment manufacturers have established recommended and allowable conditions for air delivered to the intake of the computing equipment
- Some manufacturers design for even harsher conditions
- Design for computer comfort – not people comfort
- Most data center computer room air conditioners are controlling the air returning to the unit



Environmental conditions

- Prior to ASHRAE’s Thermal Guidelines, there were NO published multi-vendor or vendor neutral temperature and humidity guidelines.
- Perceptions today lead many data centers to operate much cooler than necessary; often less than 68 °F.
- ASHRAE’s Thermal Guidelines have a RECOMMENDED temperature range of 18 °C (64.4 °F) to 27 °C (80.6 °F).
- The Recommended Range is a “statement of reliability” which means that operating within the range is safe.
- Although this wider band may feel strange, it is endorsed by IT manufacturers and can potentially enable SIGNIFICANT energy savings such as the use of economizers.



<u>Relative Scale Comparison – Rack to Room</u>

Assume a Rack at 10 square feet

Assume a Room at 5,000 to 10,000 square feet

Relative scale difference is 1,000 to 1

Table 2.1 - Equipment Environment Specifications							
Class	Product Powered 'On' - 2008 Recommended Environmental Envelope						
	Dry Bulb Temperature ^{o}C (^{o}F)		% Relative Humidity		Recommended Dew Point ^{o}C (^{o}F)		Max Rate of Change ^{o}C (^{o}F) / hr
	Allowable	Recommended	Allowable	Recommended	Minimum	Maximum	
1	15 to 32 (59 to 90)	18 to 27 (64 to 81)	20 to 80	Max. 60	5.5 (42)	15 (59)	5 (9)
2	10 to 35 (50 to 95)	18 to 27 (64 to 81)	20 to 80	Max. 60	5.5 (42)	15 (59)	5 (9)
3	5 to 35 (41 to 95)	NA	8 to 80	NA	NA	28 (82)	NA
4	5 to 40 (41 to 104)	NA	8 to 80	NA	NA	28 (82)	NA

Environmental Specifications are based on a maximum elevation of 3,050 meters
(10,000 feet)

Example server specification:
(Dell PowerVault MD3000)

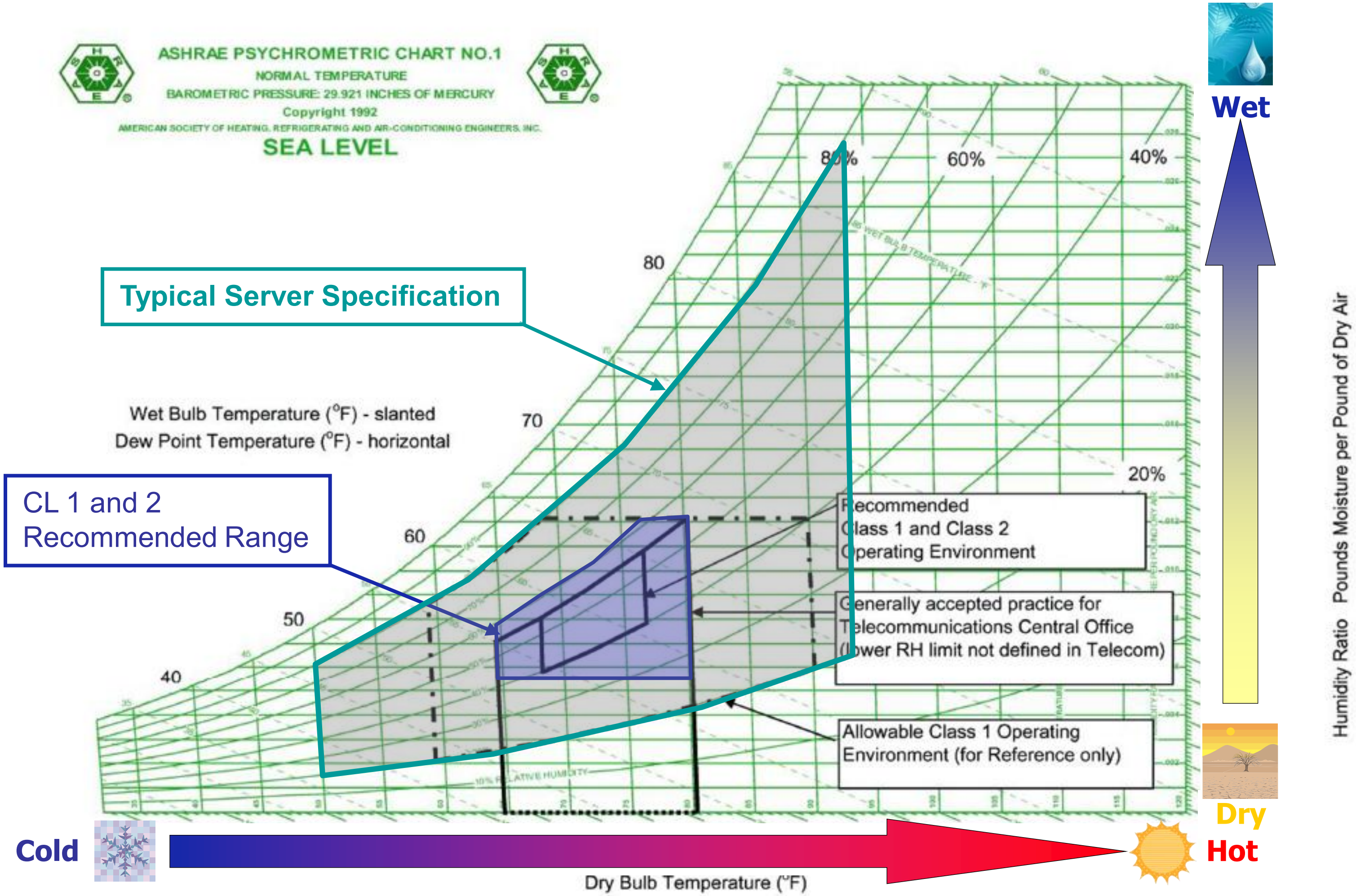
Environmental

Temperature:
- Operating: 10° to 35°C (50° to 95°F)
- Storage: -40° to 65°C (-40° to 149°F)

Relative humidity
- Operating: 20% to 80% (non-condensing)
- Storage: 5% to 95% (non-condensing)

Altitude
- Operating: -15 to 3048 m (-50 to 10,000 ft)
- Storage: -15 to 10,668 m (-50 to 35,000 ft)

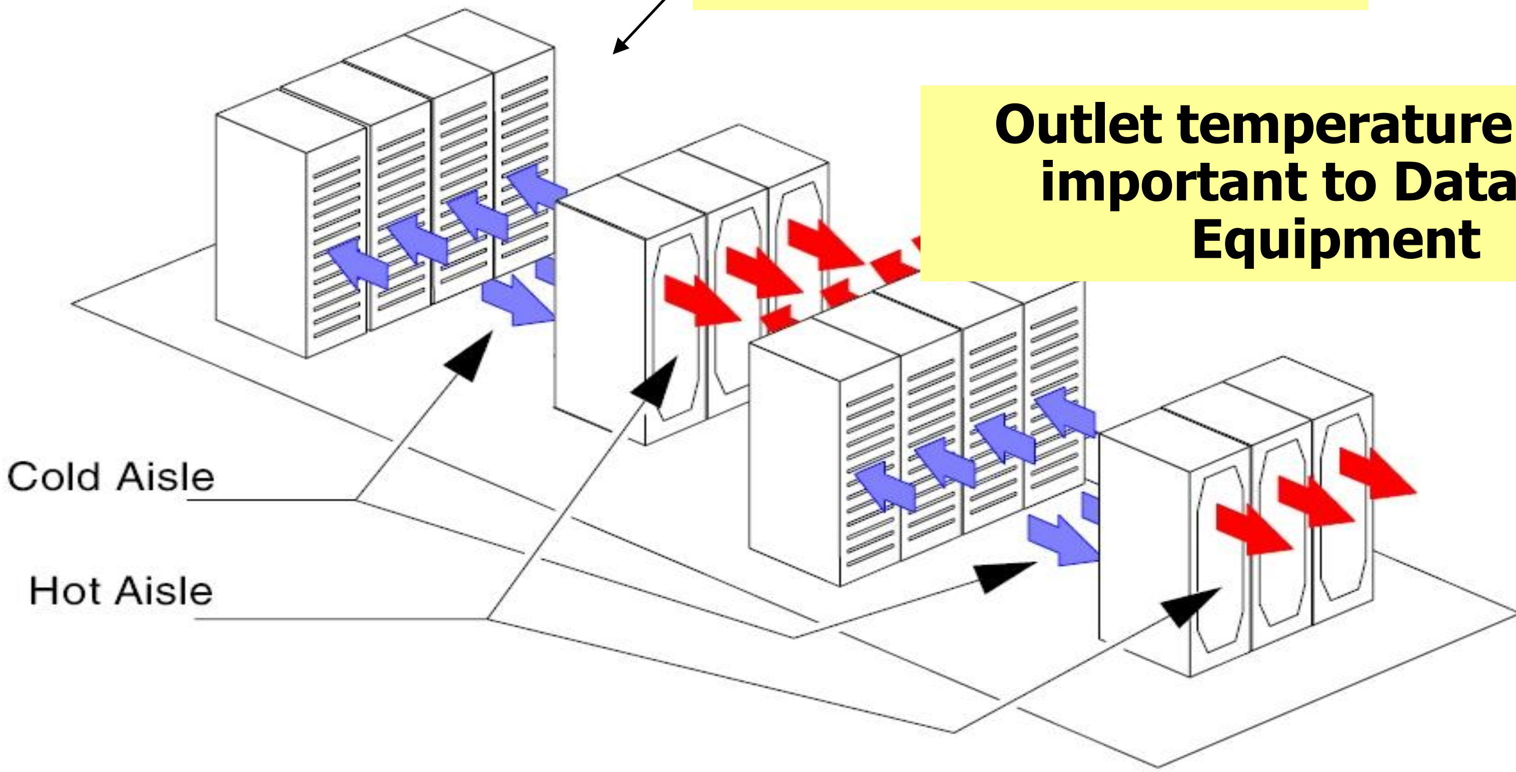
Server specs exceed ASHRAE ranges



Equipment Environmental Specification - measurement location-

<u>Air Inlet</u> to Datacom Equipment is the important specification to meet

Outlet temperature is not important to Datacom Equipment



Lower humidity limit

Electrostatic discharge (ESD)

- IT equipment is qualified for ESD
- Recommended mitigation procedures
  - Personnel grounding
  - Cable grounding
- Recommended equipment
  - Grounding wrist straps on racks
  - Grounded plate for cables
  - Grounded flooring
  - Servers rated for ESD resistance
- Industry practices
  - Telecom industry has no lower limit
  - The Electrostatic Discharge Association has removed humidity control as a primary ESD control measure in their ESD/ANSI S20.20 standard

Lower humidity limit

- Tight humidity control is a legacy issue from days when paper products and tape were widely used
- Humidity controls are a point of failure and are hard to maintain
- Many data centers today operate without humidification
- More research is needed
- Humidity may be required for some physical media (tape storage, printing and bursting)
  - Old technology not found in many data centers
  - It is best to segregate these items rather than humidify the entire data center

High humidity limit

- Some contaminants (hydroscopic salts) in combination with high humidity can (over time) deposit and bridge across circuits causing current leakage or shorts.
- Operating with very high humidity (≥80%) in a contaminated environment with hydroscopic salts for long periods of time could lead to failures.
- Laws eliminating lead may be leading to more problems - more research is needed to determine further recommendations.
- Environmental monitoring and equipment hardening could be alternatives

Microsoft's data center in a tent

http://www.datacenterknowledge.com/archives/2008/09/22/new-from-microsoft-data-centers-in-tents/

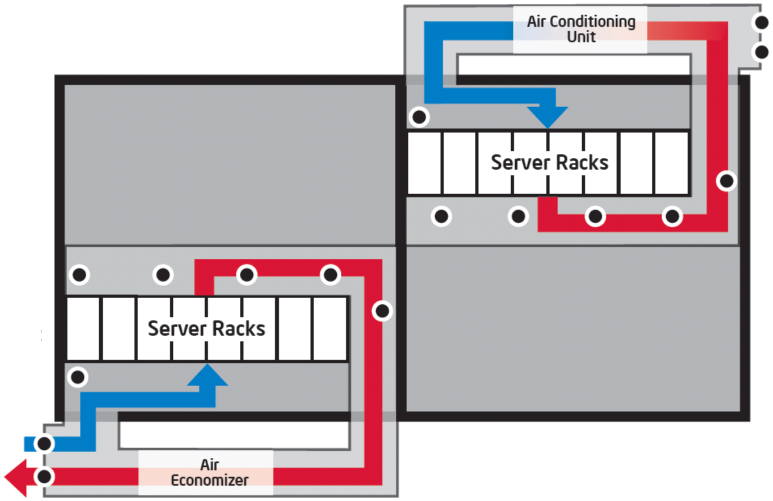
"Inside the tent, we had five HP DL585s running Sandra from November 2007 to June 2008 and we had **ZERO failures** or 100% uptime. In the meantime, there have been a few anecdotal incidents:

- Water dripped from the tent onto the rack. The server continued to run without incident.
- A windstorm blew a section of the fence onto the rack. Again, the servers continued to run.
- An itinerant leaf was sucked onto the server fascia. The server still ran without incident."

Intel's side-by-side comparison

Intel conducted a 10-month test to evaluate the impact of using only outside air to cool a high-density data center, even as temperatures ranged between 64 and 92 degrees and the servers were covered with dust.

- Intel's result: "We observed no consistent increase in server failure rates as a result of the greater variatio in temperature and humidity, and the decrease in air quality," Intel's Don Atwood and John Miner write in their white paper. "This suggests that existing assumptions about the need to closely regulate these factors bear further scrutiny



See http://www.datacenterknowledge.com/archives/2008/09/18/intel-servers-do-fine-with-outside-air/

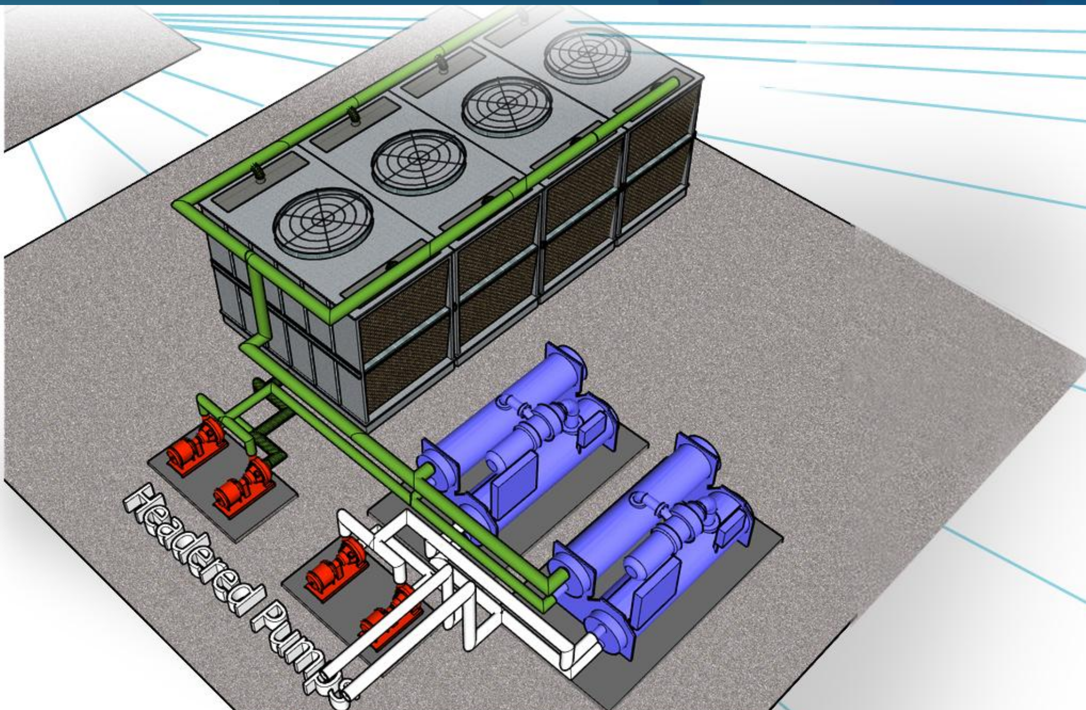
Bay area data centers without humidification controls

A dozen different organizations including:

- Banks
- Medical service provider
- Server manufacturers
- Software firms
- Colocation facilities
- Major chip manufacturer
- Supercomputer facilities
- Animation studio

Environmental conditions take aways

- Use the entire ASHRAE recommended range in data center operation.
  - Provide the warmest supply temperatures that satisfy the equipment inlet conditions.
  - Control to the widest humidity range.
  - Be aware of rate of change
- Humidification does not protect against ESD - consider grounding and personnel practices in lieu of humidification.
- More research is needed to determine optimal environmental conditions
- Isolate equipment that needs tighter humidity or temperature control.



HVAC System Design

Overview and Air Systems

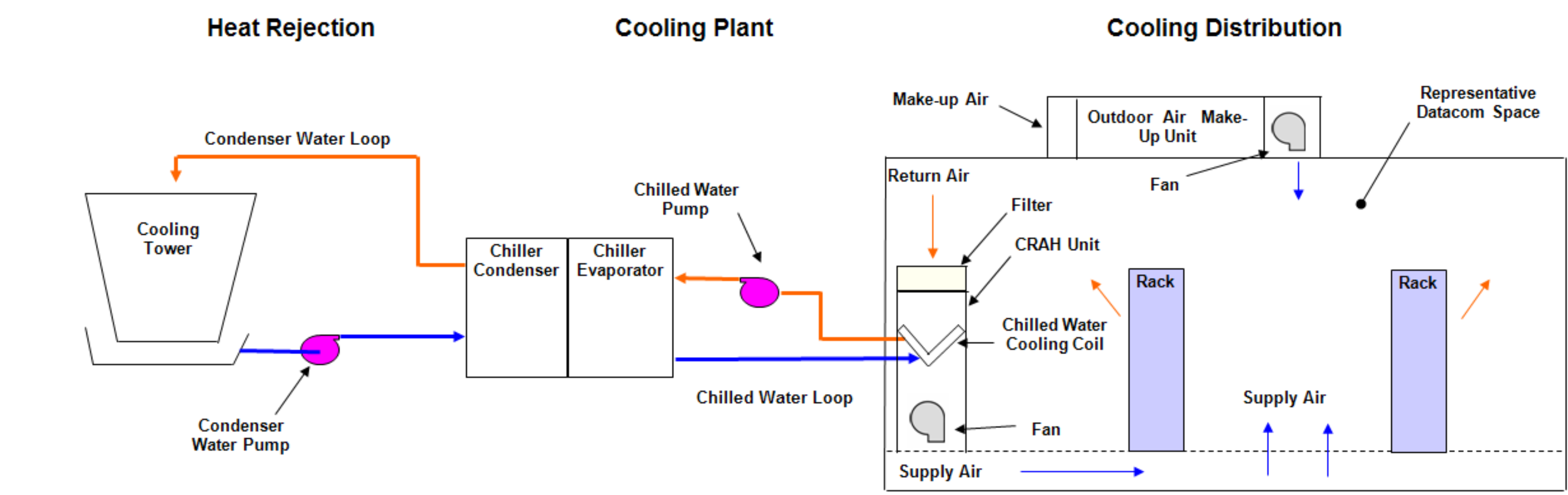
Mark Hydeman, P.E., FASHRAE

Taylor Engineering

HVAC system design

- HVAC system overview
- Data center layout
- Airflow configurations
  - Distribution: overhead or underfloor
  - Control: constant or variable volume
- Aisle containment
- Use of custom units

HVAC system overview



Heat Rejection Alternatives:

High Eff

- Water Cooled Direct (shown)
- Water Cooled Indirect (with HX)
- Evaporatively Cooled
- Air Cooled
- Dry Cooler (Air Cooled with Glycol)

η

Low Eff

Cooling Plant Alternatives:

- Water-Side Economizer (HX)
- Chiller (shown)
- Direct Expansion (DX)

Terminal Unit Alternatives

- Liquid Cooling
- Central AHU
- CRAH Unit (shown)
- CRAC Unit (DX)

Distribution Alternatives

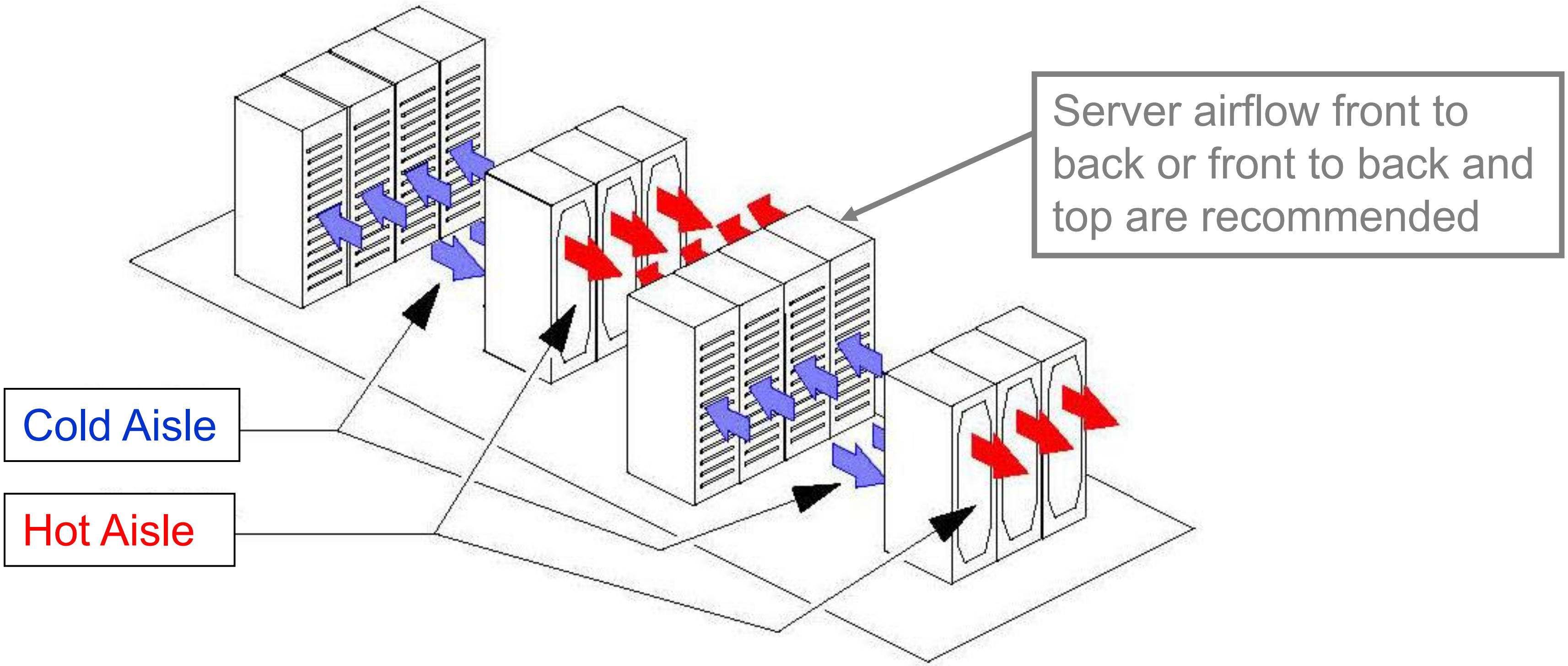
High Eff

- On Board
- In Rack
- In Row
- Overhead Air
- Underfloor Air (Shown)

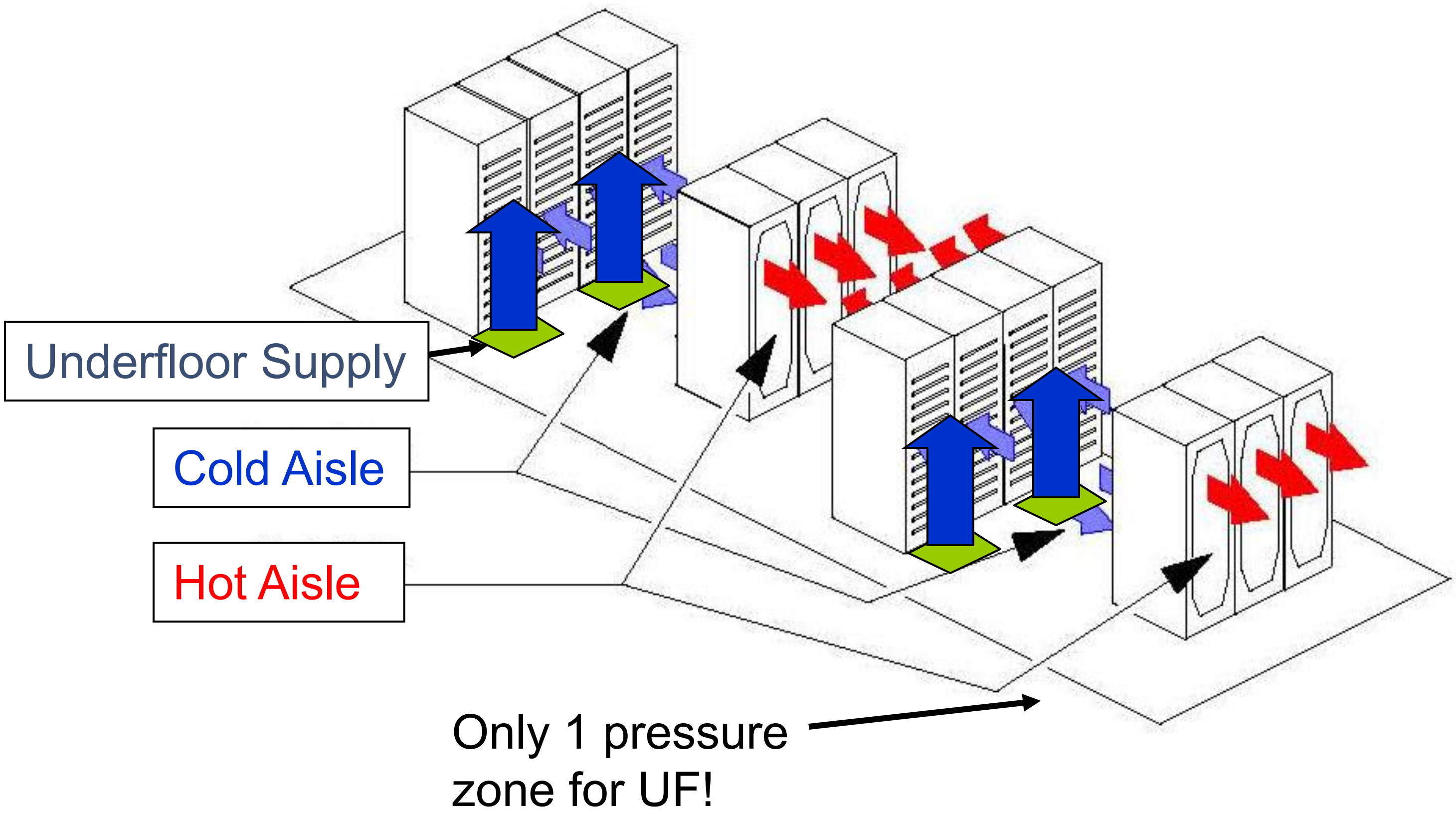
η

Low Eff

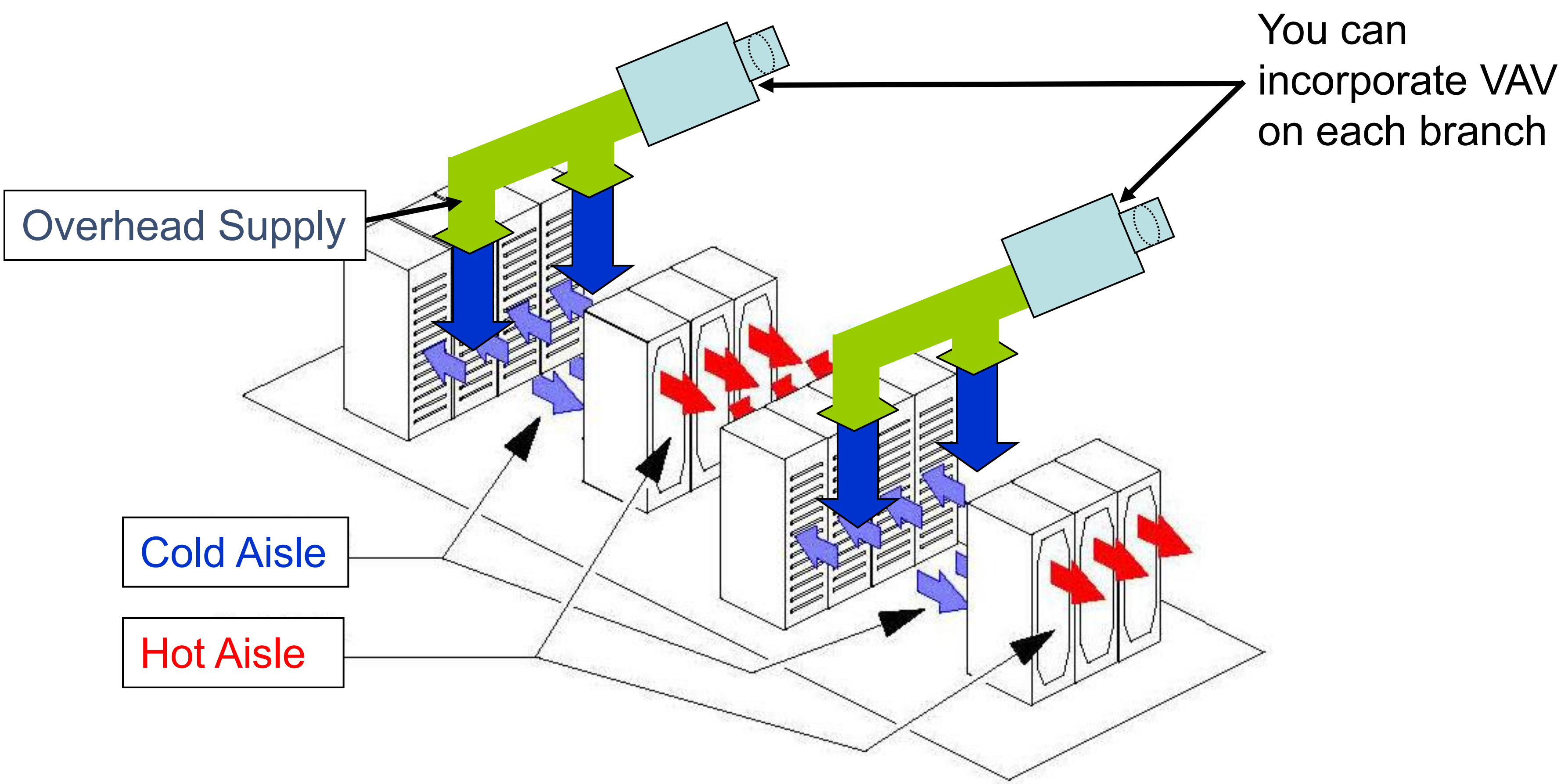
Data center layout



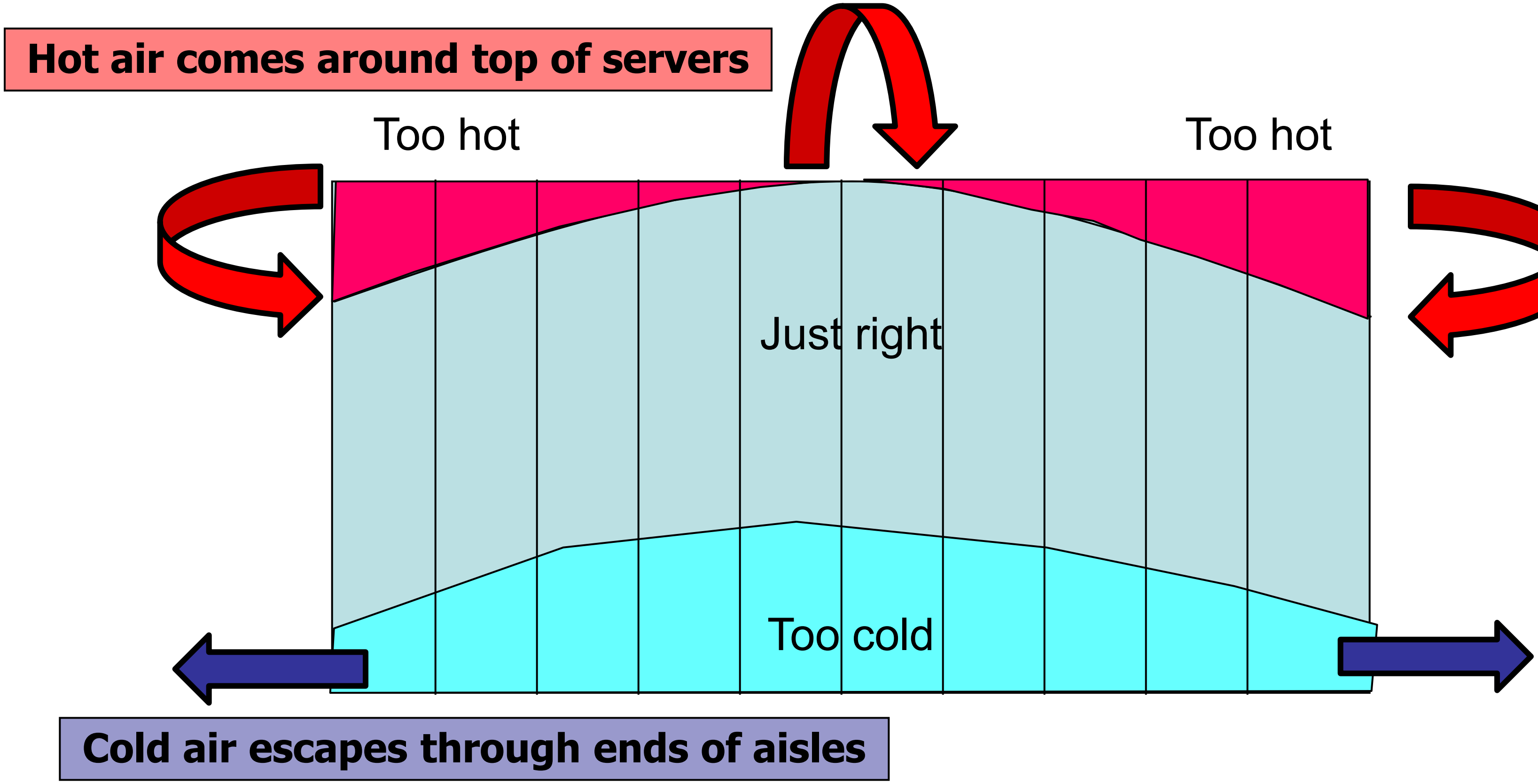
Underfloor supply



Overhead supply



Typical temperature profile with underfloor supply

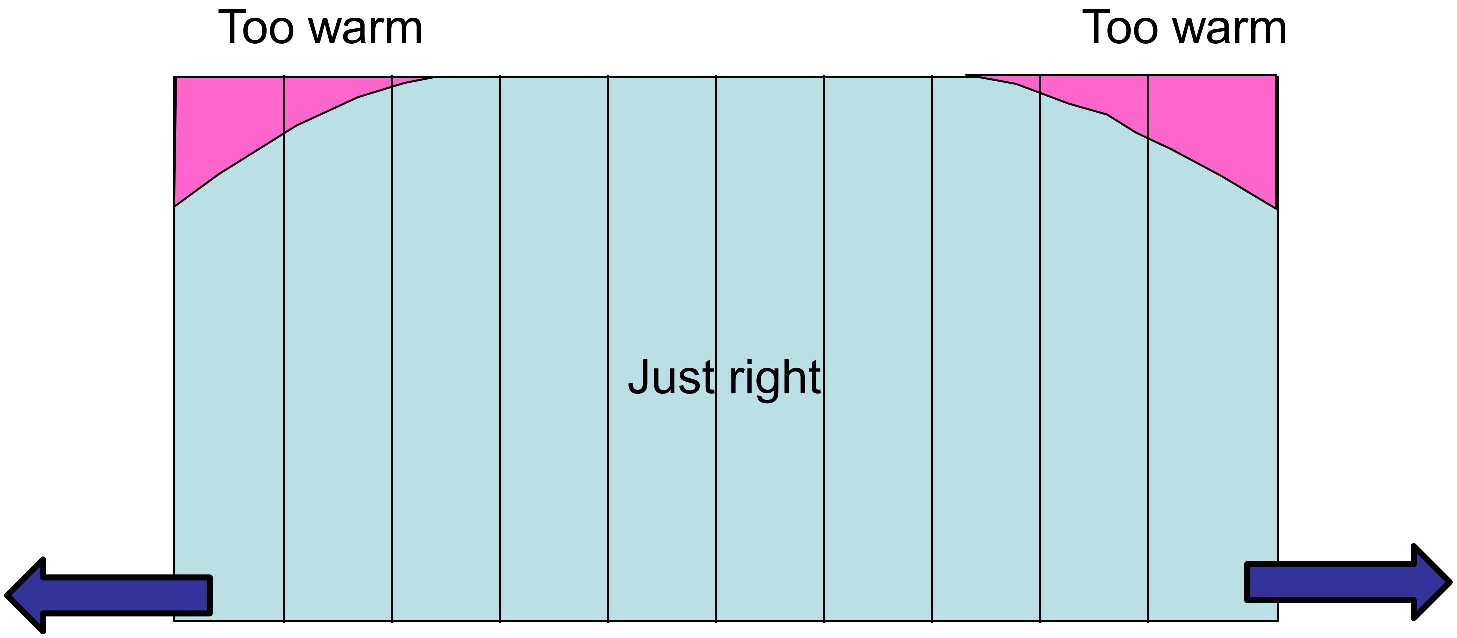


Elevation at a cold aisle looking at racks

There are numerous references in ASHRAE. See for example V. Sorell et al; "Comparison of Overhead and Underfloor Air Delivery Systems in a Data Center Environment Using CFD Modeling"; ASHRAE Symposium Paper DE-05-11-5; 2005

Typical temperature profile with overhead supply

Overhead supply tends to mix air better



Cold air still escapes through ends of aisles

Elevation at a cold aisle looking at racks

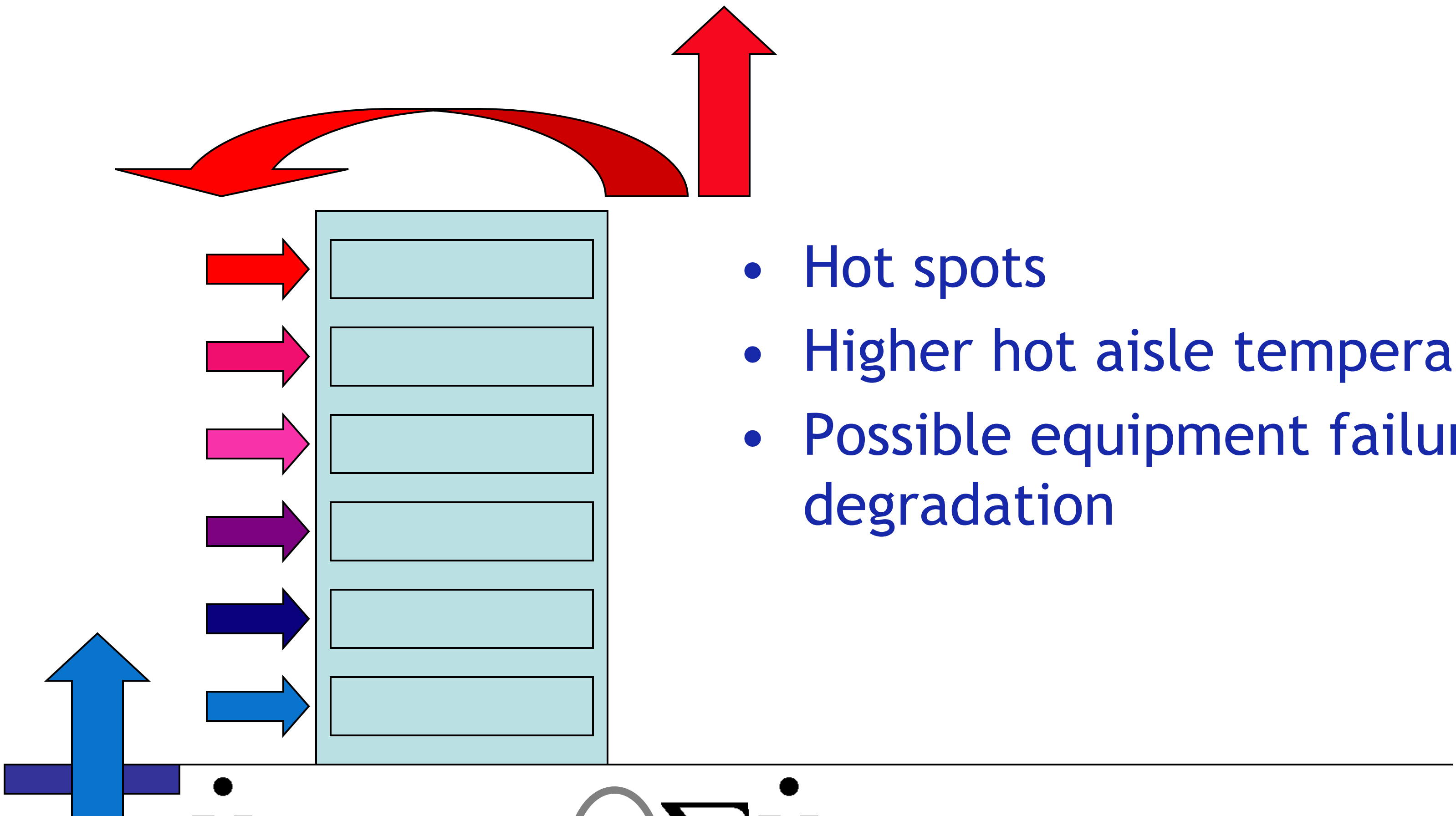
Overhead (OH) vs. underfloor (UF)

Issue	**Overhead (OH) Supply**	**Underfloor (UF) Supply**
Capacity	Limited by space and aisle velocity.	Limited by free area of floor tiles.
Balancing	Continuous on both outlet and branch.	Usually limited to incremental changes by diffuser type. Some tiles have balancing dampers. Also underfloor velocities can starve floor grilles!
Control	Up to one pressure zone by branch.	Only one pressure zone per floor, can provide multiple temperature zones.
Temperature Control	Most uniform.	Commonly cold at bottom and hot at top.
First Cost	Best (if you eliminate the floor).	Generally worse.
Energy Cost	Best.	Worst.
Flexibility	Harder to reconfigure	Easiest
Aisle Capping	Hot or cold aisle possible.	Hot or cold aisle possible.

Airflow design disjoint

- IT departments select servers and racks – each having airflow requirements
- Engineers size the facility fans and cooling capacity
- What's missing in this picture?

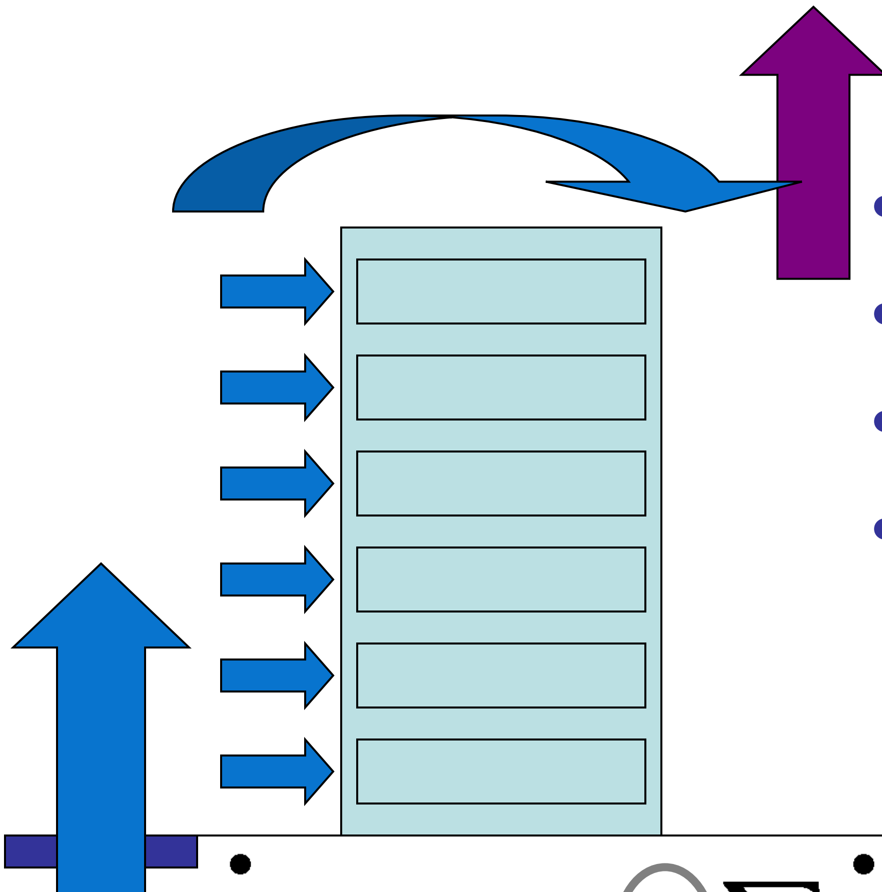
What happens when the HVAC systems have less airflow than the servers?



$$\dot{V}_{HVAC\_Supply} < \sum \dot{V}_{Servers}$$

- Hot spots
- Higher hot aisle temperature
- Possible equipment failure or degradation

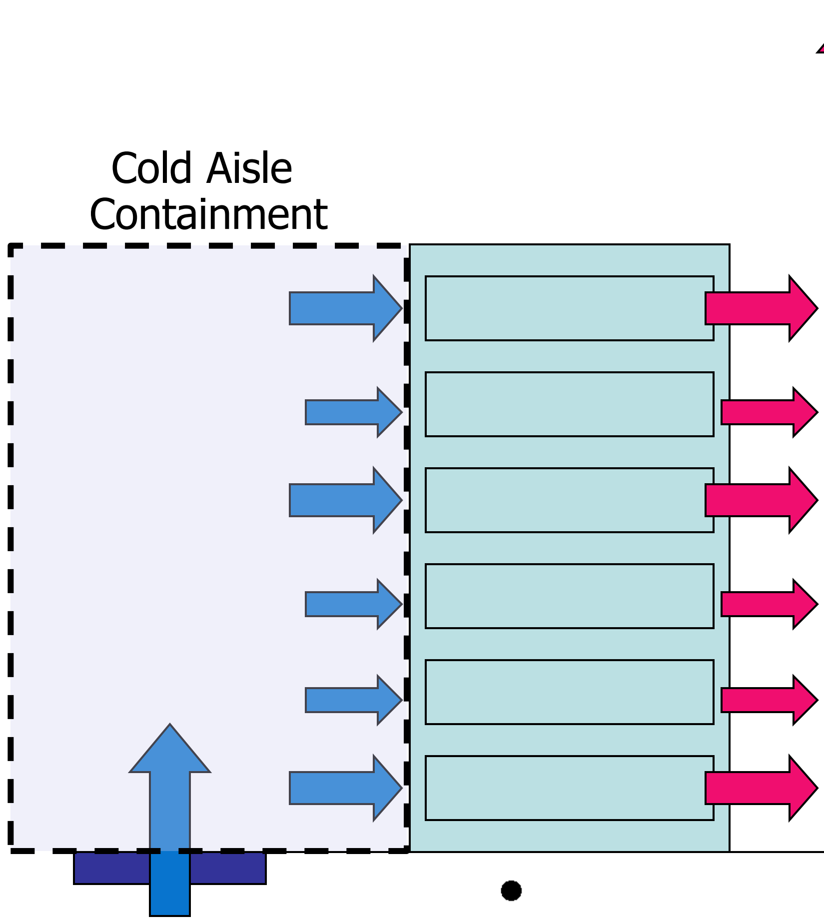
What happens when the HVAC systems have more airflow than the servers?



- Less hot spots
- Higher air velocities
- Higher fan energy
- Reduced economizer effectiveness (due to lower return temperatures)

$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$

In a perfect world, variable flow supply, variable flow server fans and air containment



- Partial flow condition
- Best energy performance
- Hard to control
- Works best with aisle containment

$$\dot{V}_{HVAC\_Supply} \approx \sum \dot{V}_{Servers}$$

ASHRAE Thermal Report

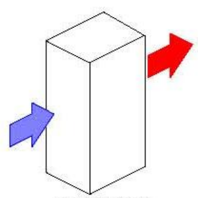
XYZ Co. Model abc Server: Representative Configurations

	Condition								
	Voltage 110 Volts								
	Typical Heat Release	Airflow[a], Nominal		Airflow, Maximum at 35°C		Weight		Overall System Dimensions[b] (W × D × H)	
Description	watts	cfm	(m^3/h)	cfm	(m^3/h)	lbs	kg	in.	mm
Minimum Configuration	*1765*	*400*	*680*	*600*	*1020*	*896*	*406*	*30 × 40 × 72*	*762 × 1016 × 1828*
Full Configuration	*10740*	*750*	*1275*	*1125*	*1913*	*1528*	*693*	*61 × 40 × 72*	*1549 × 1016 × 1828*
Typical Configuration	*5040*	*555*	*943*	*833*	*1415*	*1040*	*472*	*30 × 40 × 72*	*762 × 1016 × 1828*

ASHRAE Class

1, 2, 3

Airflow Diagram
Cooling scheme F-R



Minimum Configuration	*1 CPU-A, 1 GB, 2 I/O*
Full Configuration	*8 CPU-B, 16 GB, 64 I/O (2 GB cards, 2 frames)*
Typical Configuration	*4 CPU-A, 8 GB, 32 I/O (2 GB cards, 1 frame)*

a. The airflow values are for an air density of 1.2 kg/m^3 (0.075 lb/ft^3). This corresponds to air at 20°C (68°F), 101.3 kPA (14.7 psia), and 50% relative humidity.
b. Footprint does not include service clearance or cable management, which is zero on the sides, 46 in. (1168 mm) in the front, and 40 in. (1016 mm) in the rear.

From ASHRAE's Thermal Guidelines for Data Processing Environments

What's the IT equipment airflow?

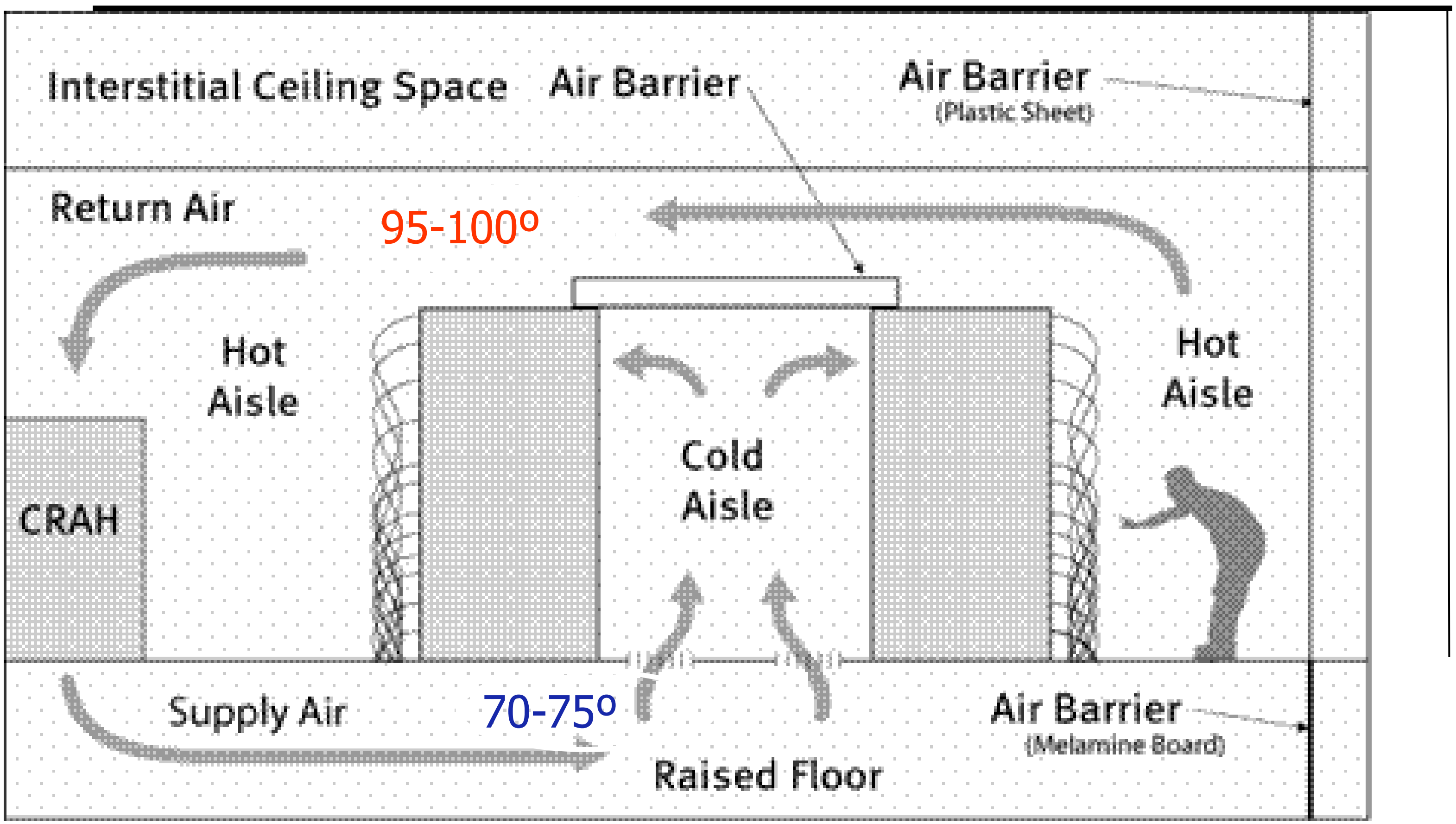
	SUN	SUN	DELL	DELL
	V490	V240	2850	6850
num fans	9	3	n/a	n/a
total CFM (max)	150	55.65	42	185
total CFM (min)			27	126
fan speed	single speed	variable	2 speed	2 speed
fan control	n/a	inlet temp.	77F inlet	77F inlet
Form Factor (in U's)	5	2	2	4
heat min config (btuh)		798		454
heat max config (btuh)	5,459	1,639	2,222	4,236
heat max (watts)	1,599	480	651	1,241
dT min config	-	13	-	3
dT max config	33	27	48	21
servers per rack	8	21	21	10
CFM/rack (hi inlet temp)	1,200	1,169	882	1,850
CFM/rack (low inlet temp)	1,200		567	1,260
max load / rack (kW)	13	10	14	12

Isolating hot or cold aisles

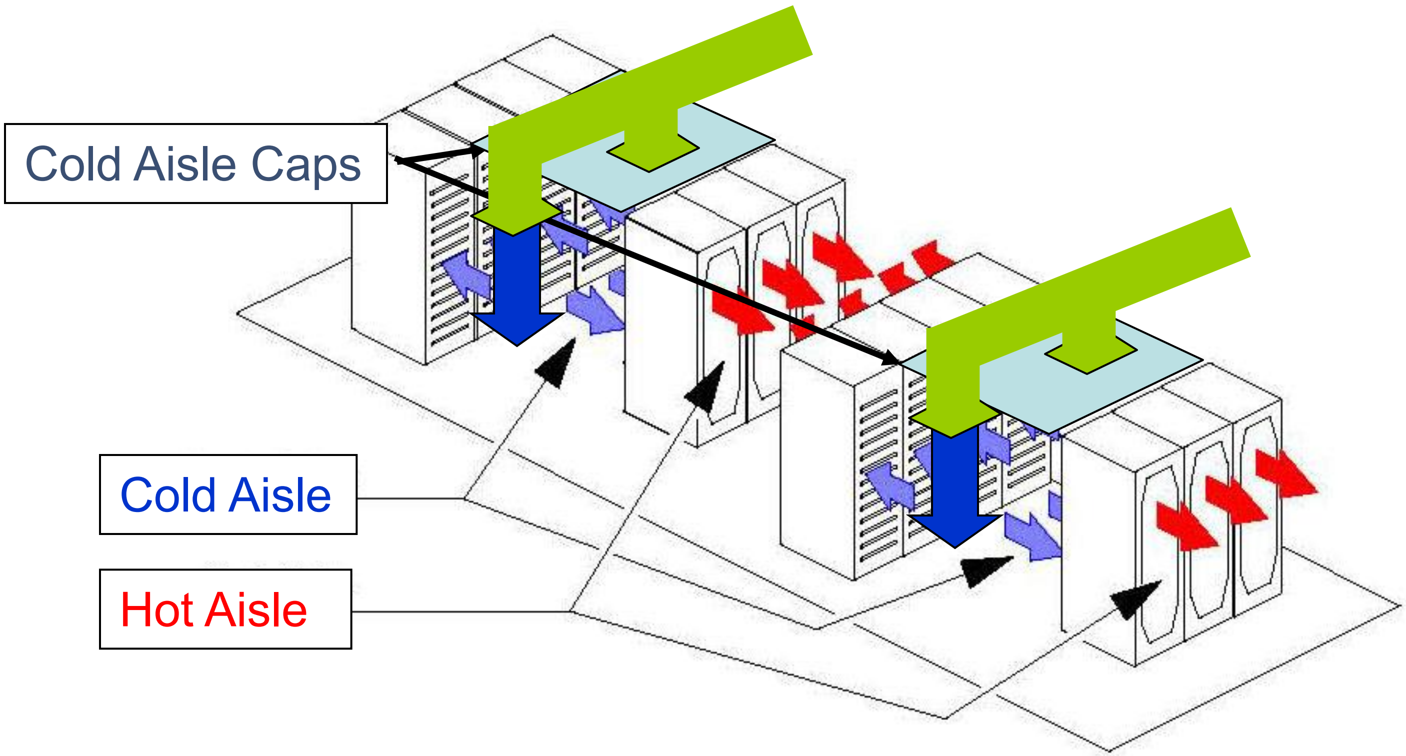
- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge.
- Supply airflow can be reduced if no mixing occurs.
- Overall temperature can be raised in the data center if air is delivered to equipment without mixing.
- Cooling systems and economizers use less energy with warmer return air temperatures.
- Cooling coil capacity increases with warmer air temperatures.

Cold aisle containment, underfloor supply

With cold aisle containment, the general data center is hot 85-100F

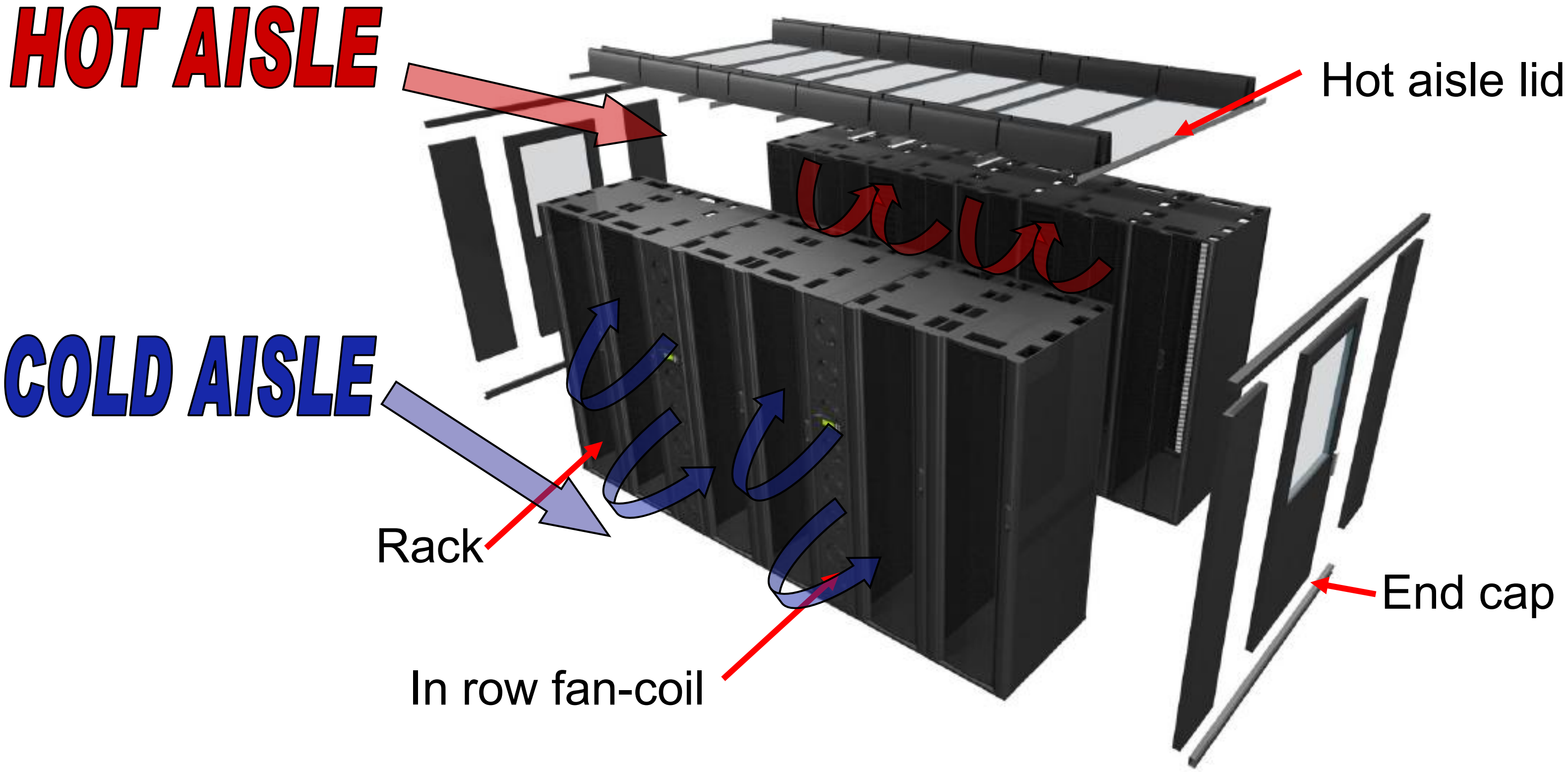


Cold aisle containment, overhead supply

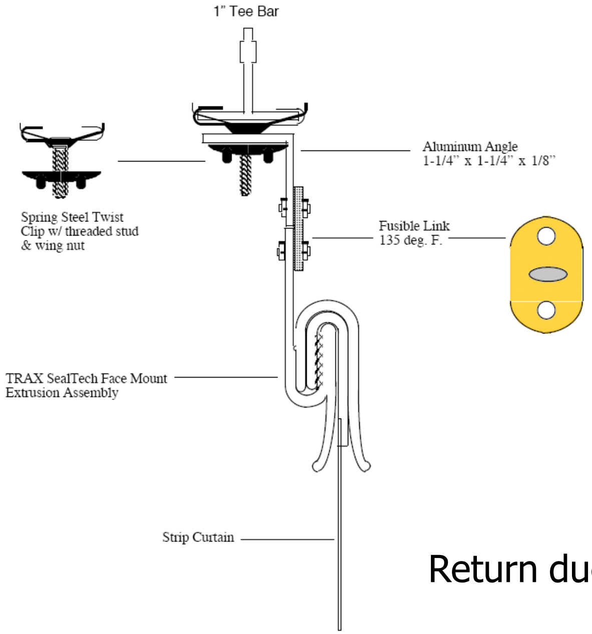


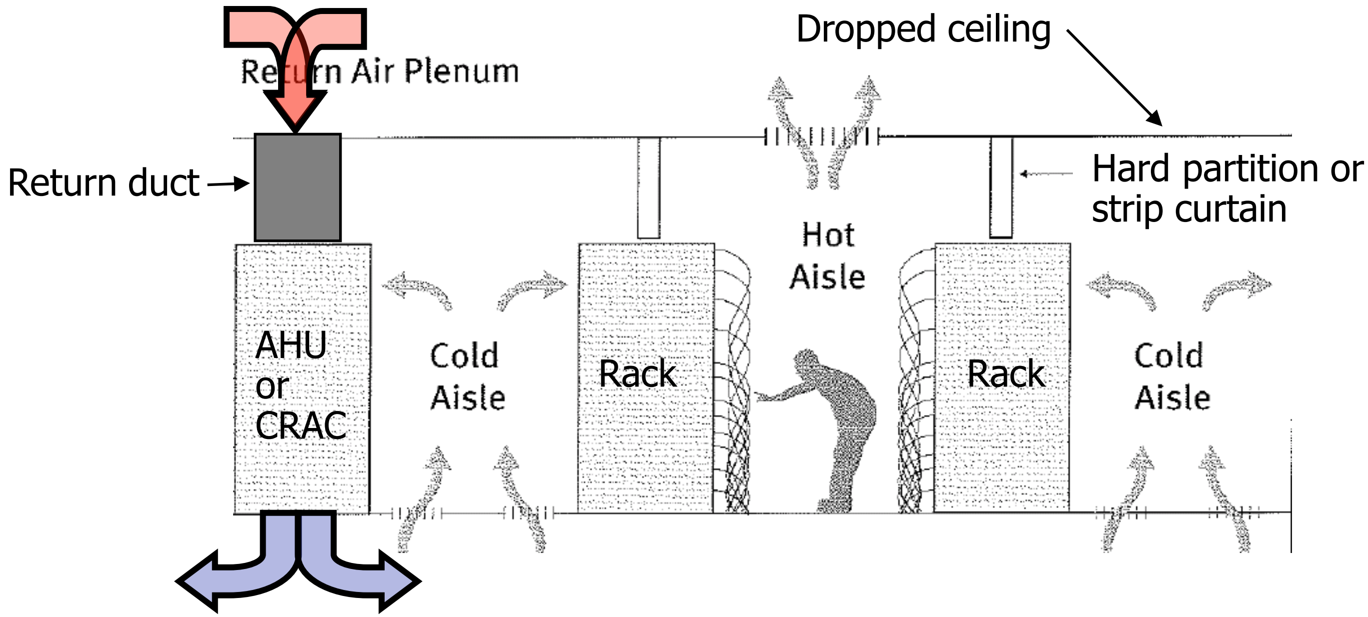
Hot aisle containment with in row cooling

With hot aisle containment, the general data center is neutral (70-75F)



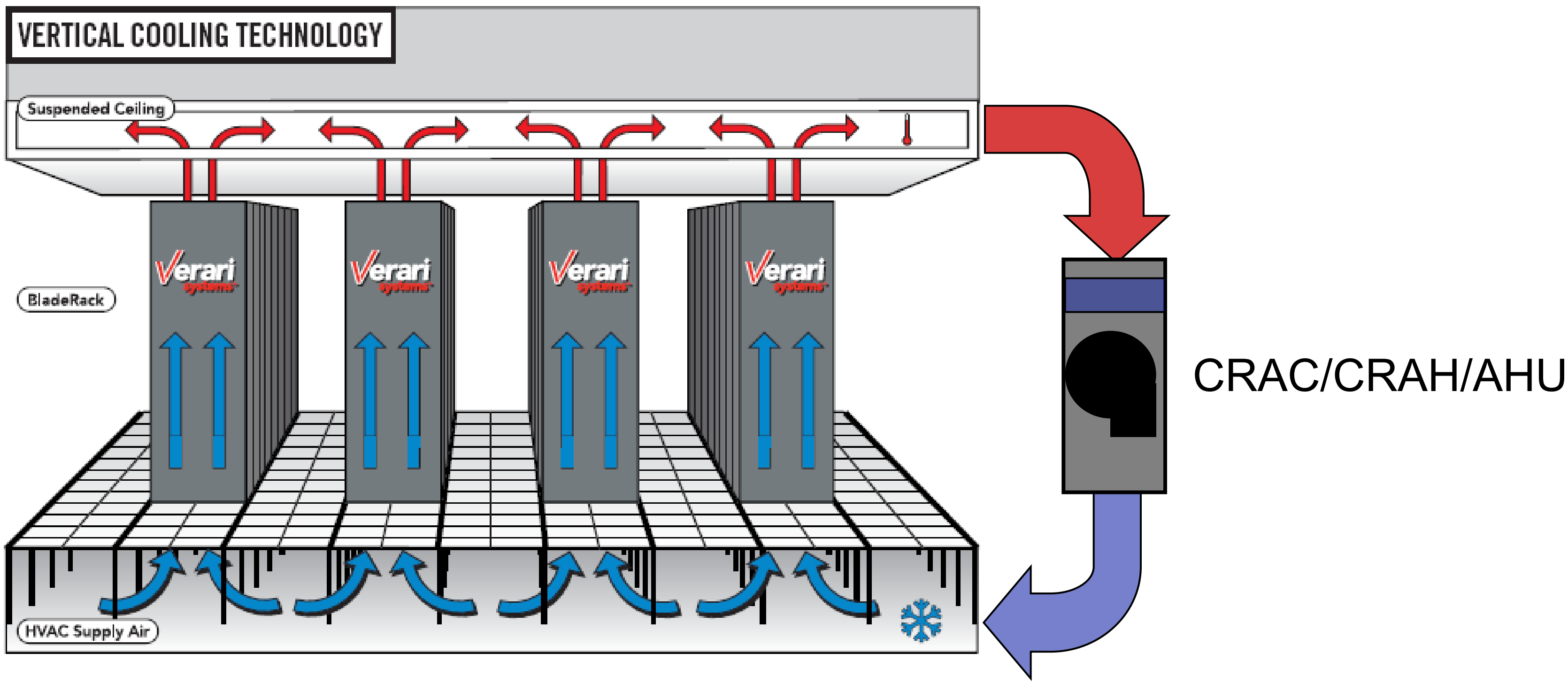
Hot aisle containment the frugal way





Combined hot and cold aisle containment

In this model the data center can be controlled for comfort



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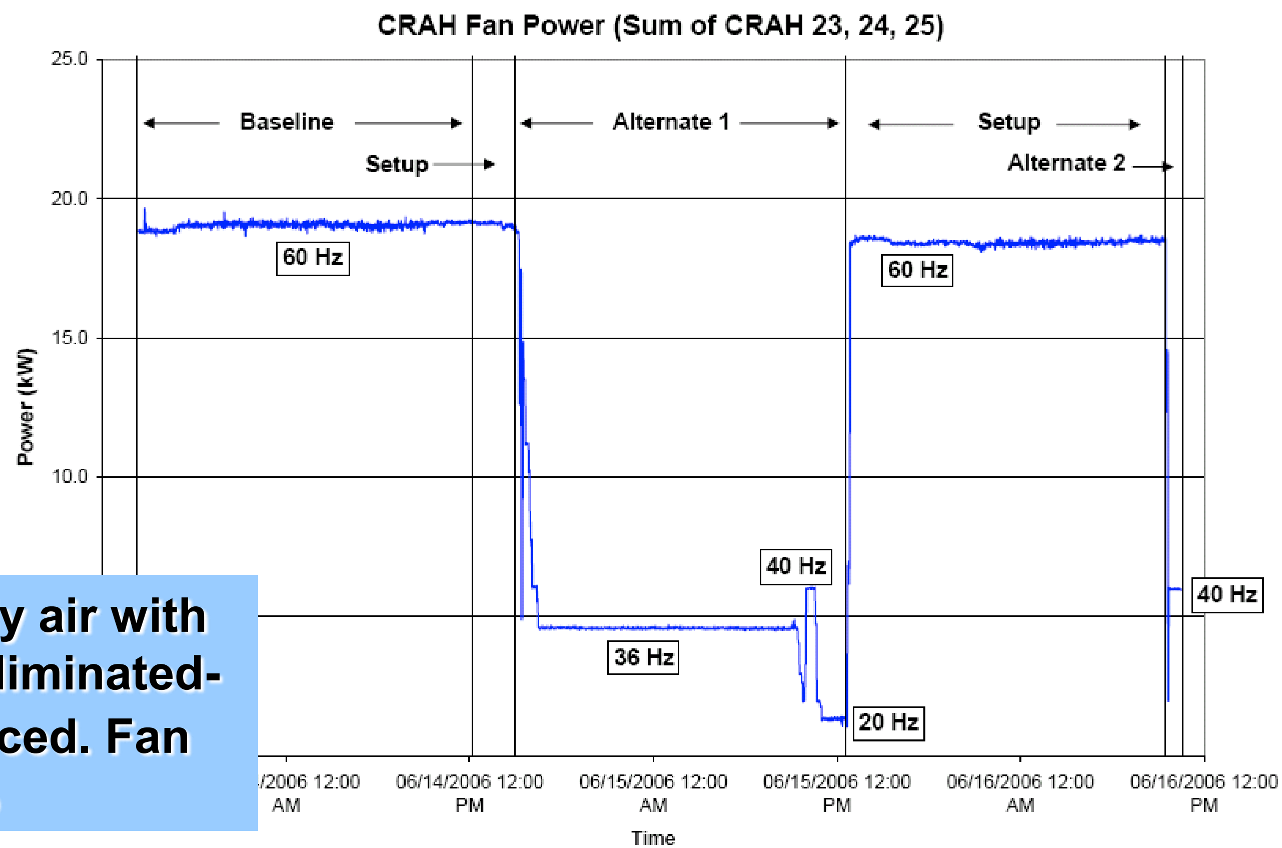
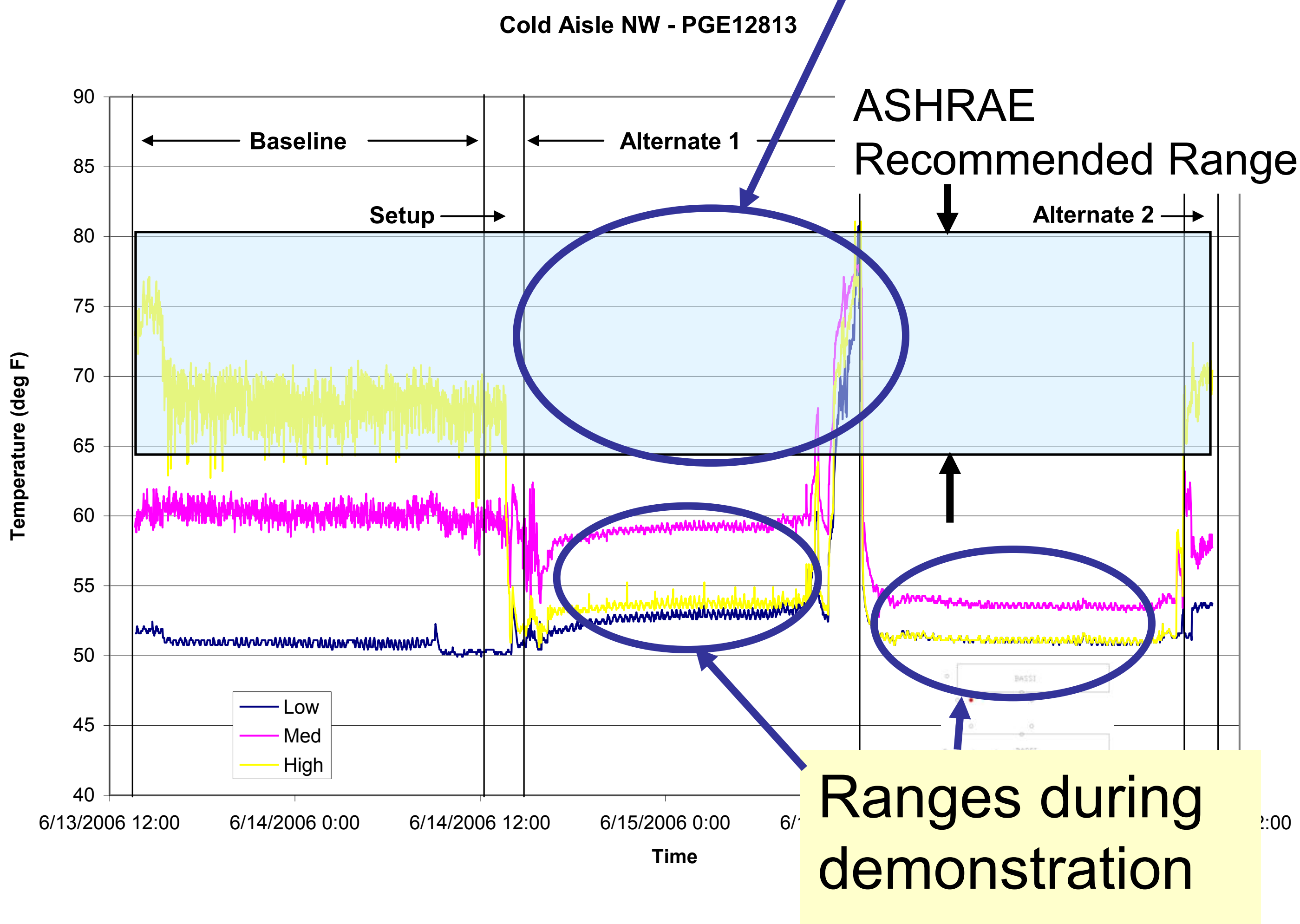
LBNL cold aisle containment demo



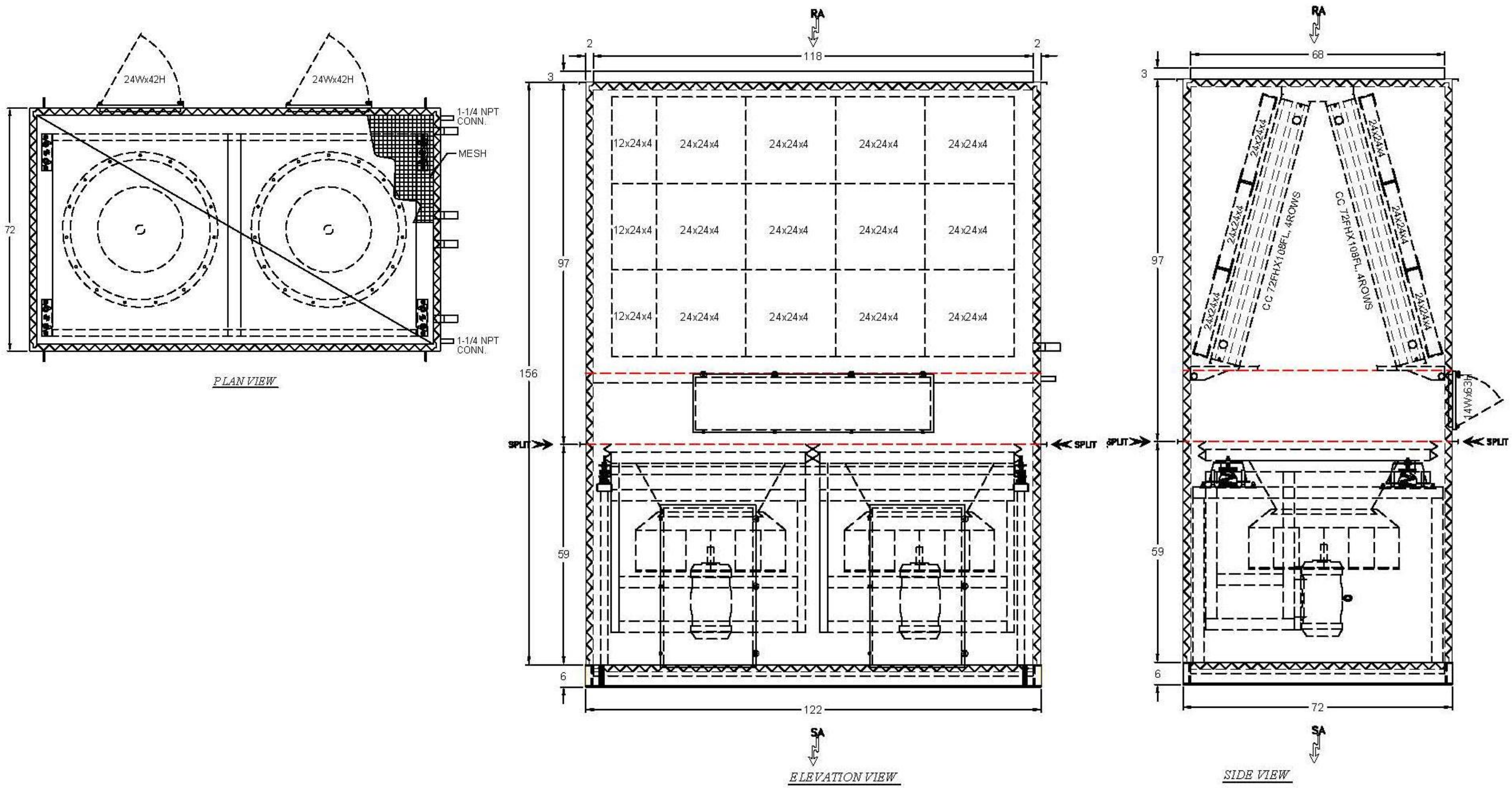
If mixing of cold supply air with hot return air can be eliminated- fan speed can be reduced. Fan Energy Savings ~ 75%

LBNL cold aisle containment demo

Better airflow management permits warmer supply temperatures!



Custom air handling units



Example custom CRAH unit comparison

	Option 1	Option 2	
Model	Std CRAC	Custom Model 1	Custom Model 2
Budget Cost	$ 16,235	$ 23,000	$ 41,000
Number of units	21	13	4
net total cooling (btuh)	434,900	410,000	841,000
net sensible (btuh)	397,400	399,000	818,000
sensible (tons)	33.1	33.3	68.2
CFM	16,500	25,000	50,000
SAT	49.90	59.30	59.00
airside dT	25.10	15.70	16.00
Internal SP	2	0.8	0.8
		1.8	1.8
no. fans	3	3	2
fan type	Centrifugal	Plenum	Plenum
no. motors	1	3	2
HP/motor	15	5	15
total HP	15	15	30
BHP/motor	15	4.7	11.5
Unit BHP	15	14.1	23
unit width	122	122	122
depth	35	36	72
height	76	156	168
filter type	ASHRAE 20%	MERV 13	MERV 13
Water PD (ft)	13.5 ft	11.1	11.1
CHW dT	14F	20	20
GPM	66.80	44.00	88.00
Total GPM	1,403	924	66%
Total BHP	315	275	87%

Example CRAH unit comparison

- 34% less water flow
- 13% less fan energy
  - More if you consider the supply air temperature and airflow issues
- Excess fan capacity on new units
- 36% higher cost for units, but
  - Fewer piping connections
  - Fewer electrical connections
  - Fewer control panels
  - No need for control gateway
  - Can use the existing distribution piping and pumps
  - Can use high quality sensors and place them where they make sense

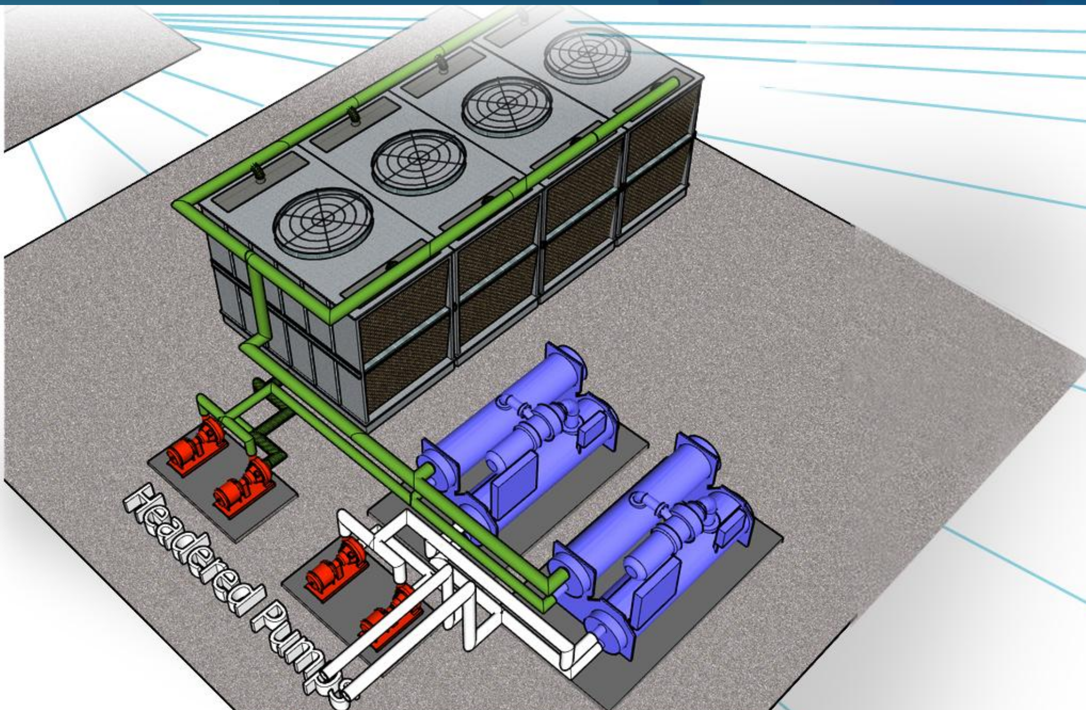
CRAH Bid 2, 39 Units (~37 tons each)

	Unit A	Unit B	B-A	(B-A)/A
First Cost	$ 779,680	$ 1,019,768	$ 240,088	31%
Airflow	666,900	702,000	35,100	5%
Fan bhp	10.65	7.6	(3.0)	-29%
Coil Flow (gpm)	59.1	44	(15)	-26%
DT (F)	15	20.1	5	34%
DP (feet)	14	7	(7)	-50%
kWh/yr	1,169,517	826,249	(343,268)	-29%
$/yr	$ 140,342	$ 99,150	$ (41,192)	-29%
NPV	$ 2,246,084	$ 2,055,764	(190,321)	-8%

- Comparison of 39 (n) CRAH units
- Unit B 30% higher installed costs but...
- Lower LCC: $40K/yr energy savings, $290K NPV
- Not included in this analysis:
  - Plant pumps dropped 50=>40hp (typ 5) and 20=>15hp (typ 6)
  - TES pipes dropped from 16”=>14” (~200 l.f. piping)
  - Chillers and pumps dropped from 10”=>8” (lots of appurtenances like valves, flow meters...)
  - 16% increase in TES ton-hrs with no change in the tank size

Best air delivery practices

- Arrange racks in hot aisle/cold aisle configuration.
- Plug leaks in floor and racks!
- Try to match or exceed server airflow by aisle.
  - Get thermal report data from IT if possible.
  - Plan for worst case.
- Get variable speed or two speed fans on servers if possible.
- Provide variable airflow fans for CRAC/H or AHU supply.
- Consider using air handlers rather than CRAHs for improved performance.
- Provide aisle capping (either hot or cold aisle works).
- Draw return from as high as possible.



Free Cooling

Mark Hydeman, P.E., FASHRAE

Taylor Engineering

Free Cooling Overview

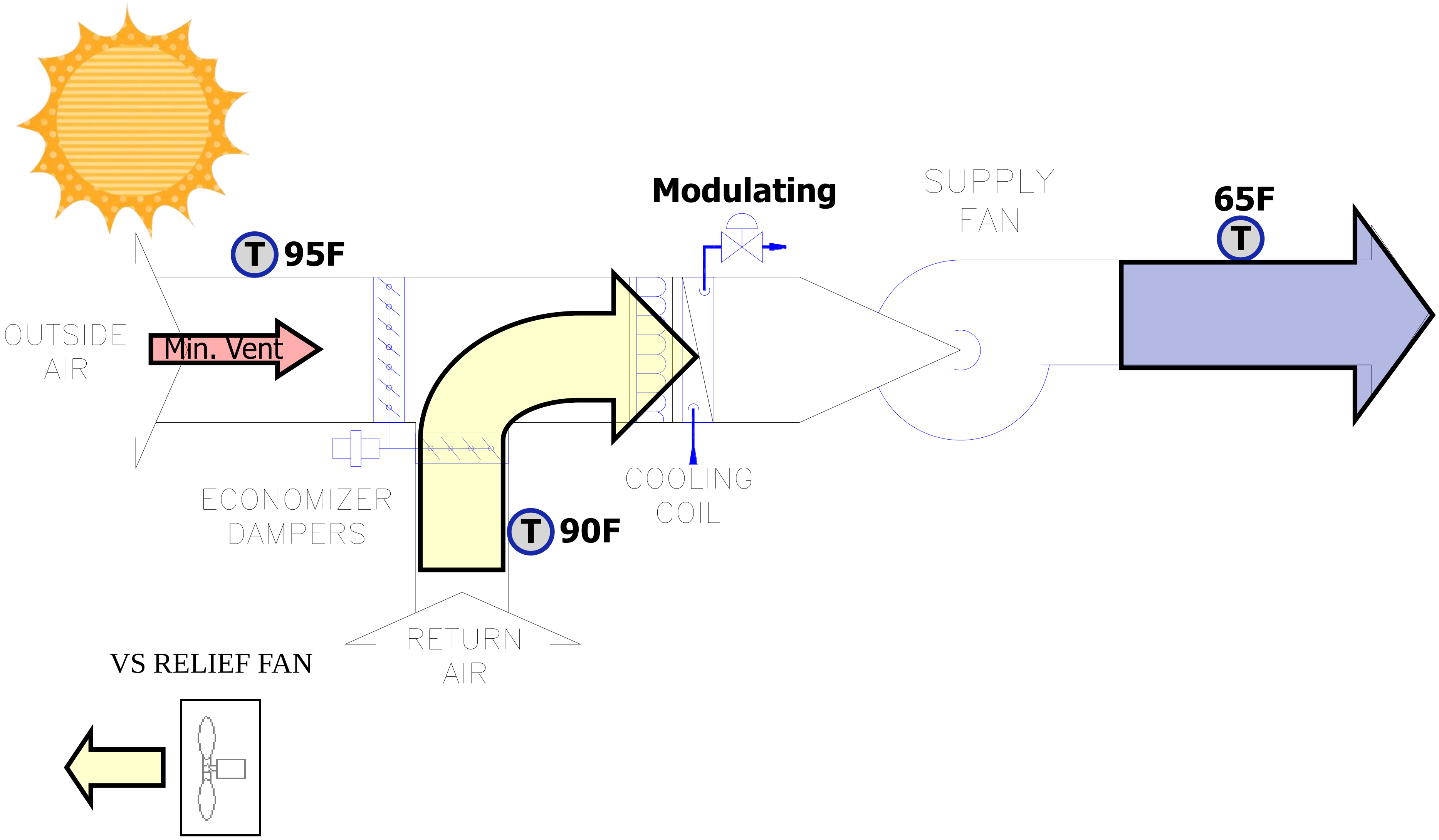
Air side economizers

- An overview of air-side economizers
- The potential energy savings of air-side economizers in the 16 ASHRAE climates
- The relationship of humidification and air-side economizers
- Challenges to implementing air-side economizers
- A combined air-side economizer with direct evaporative cooling (an emerging technology)
- Non-energy benefits of air-side economizers

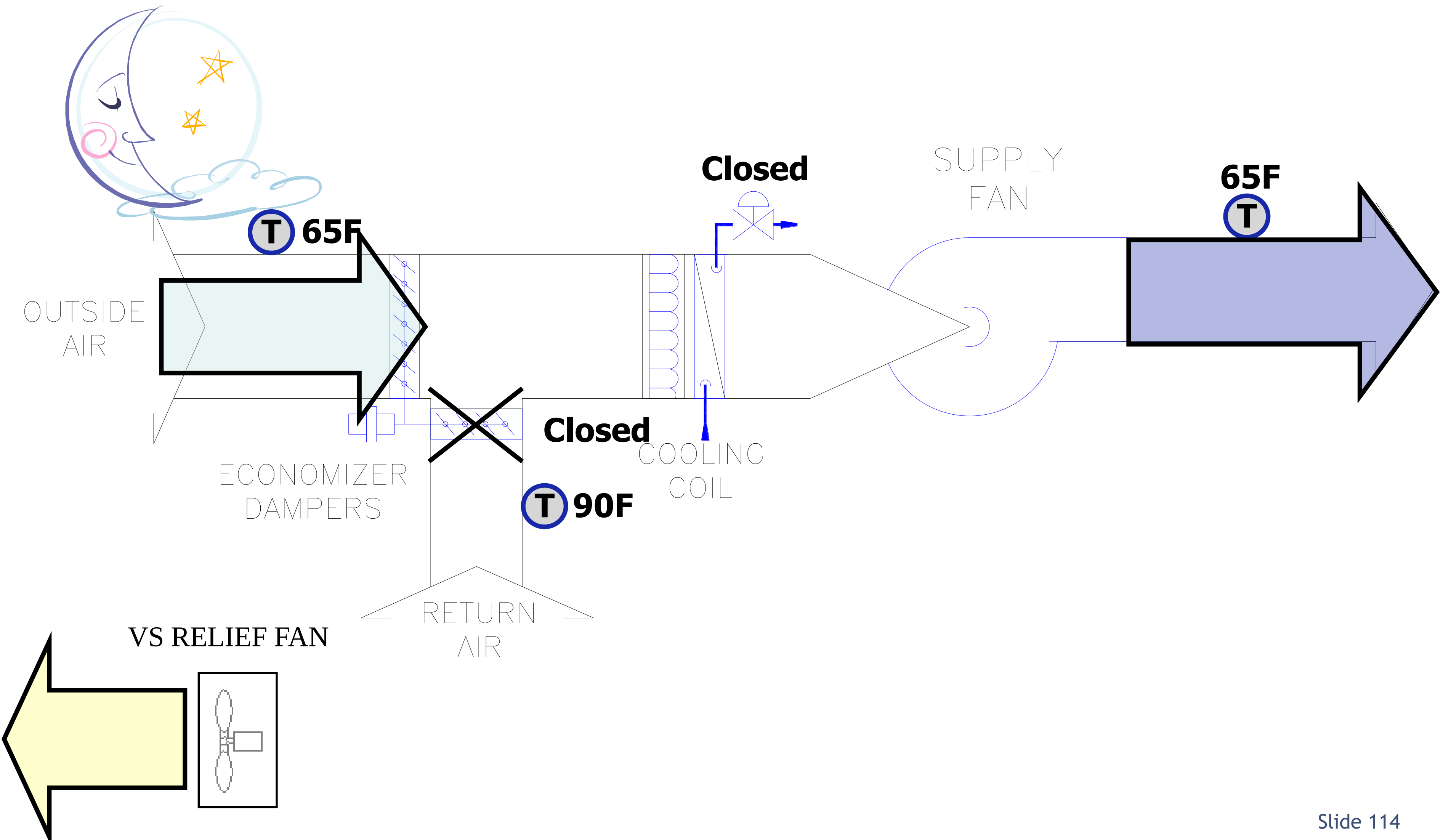
Water side economizers

- An overview of water-side economizers
- The potential energy savings of water-side economizers
- Challenges to implementing water-side economizers
- Non-energy benefits of water-side economizers

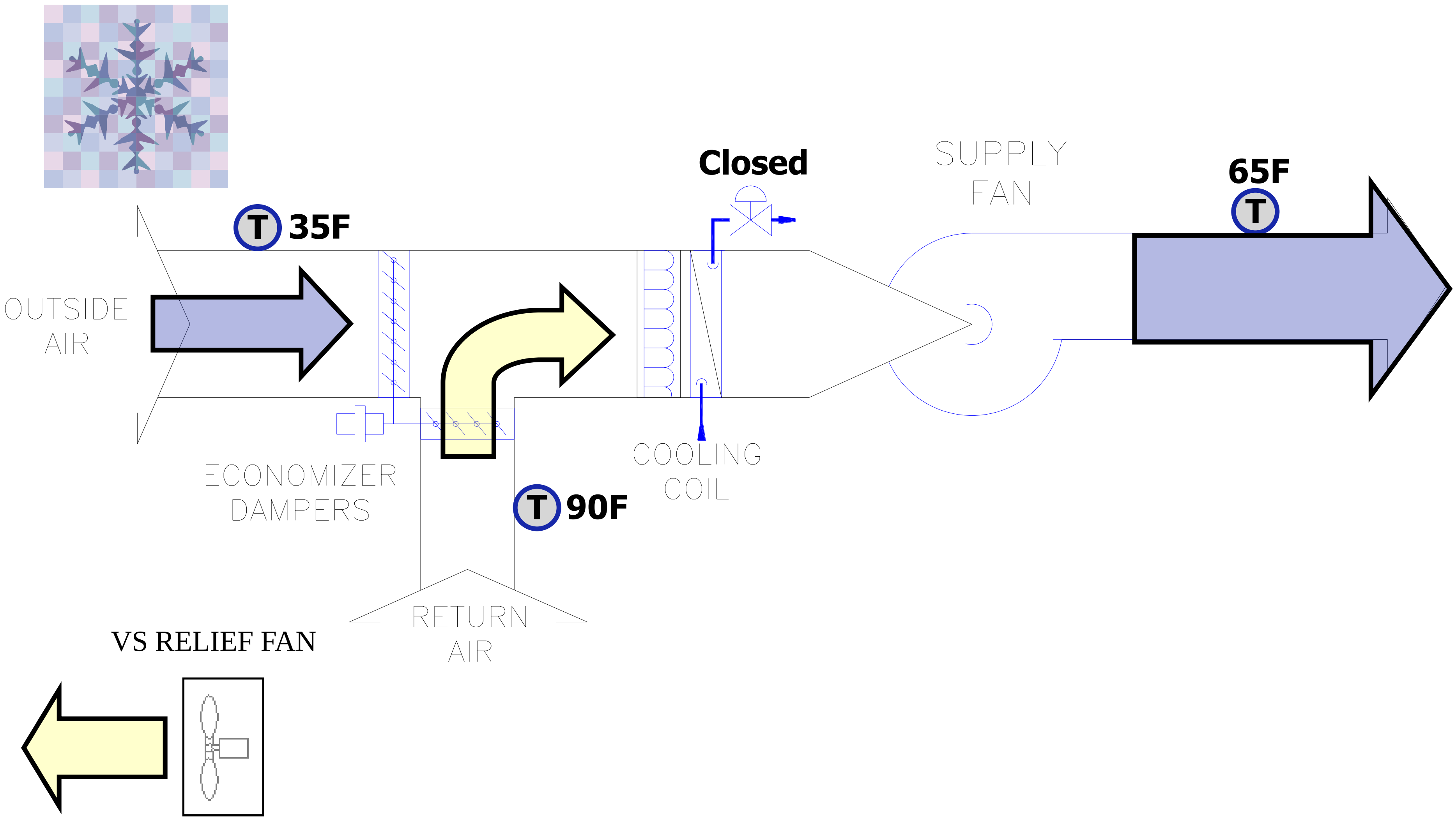
Air-side economizer



Air-side economizer



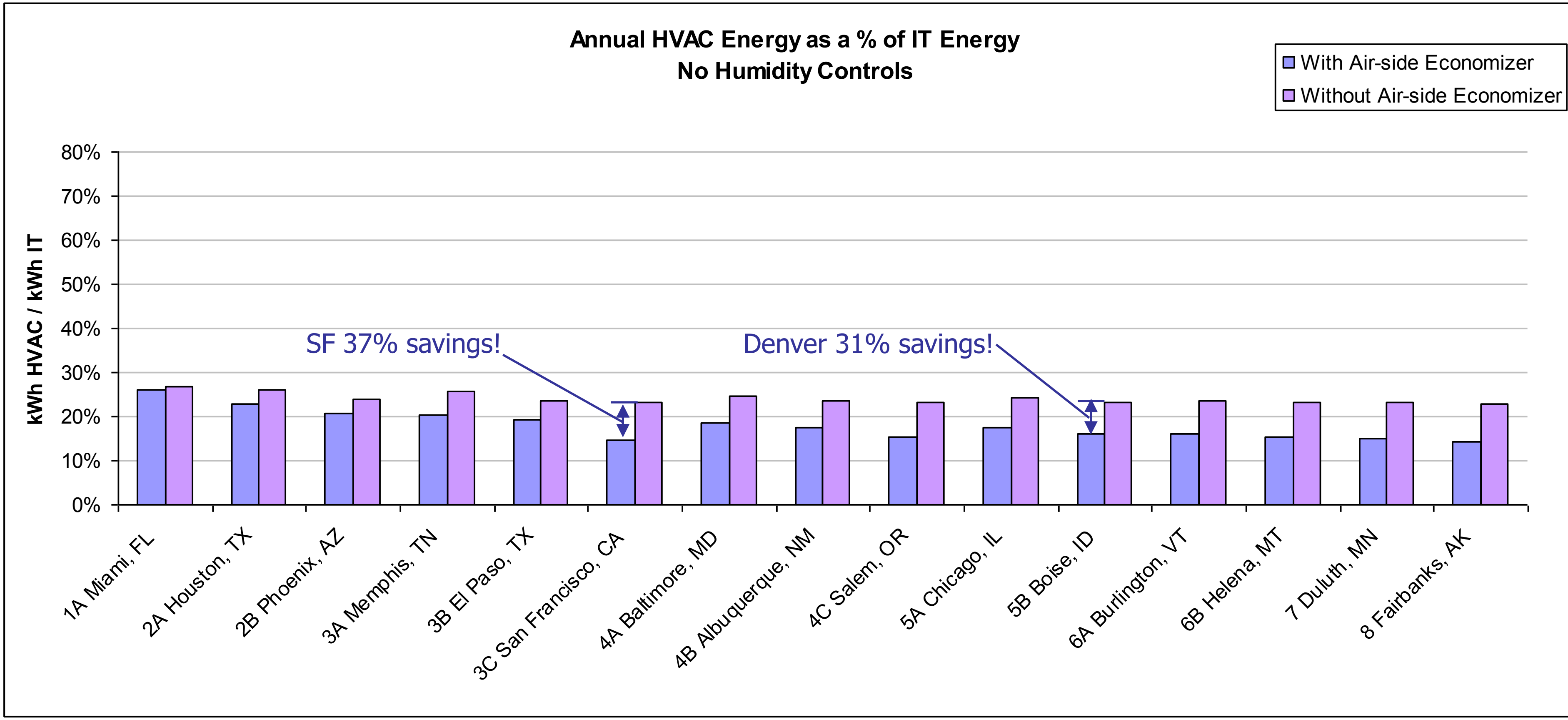
Air-side economizer



Air side economizer elements

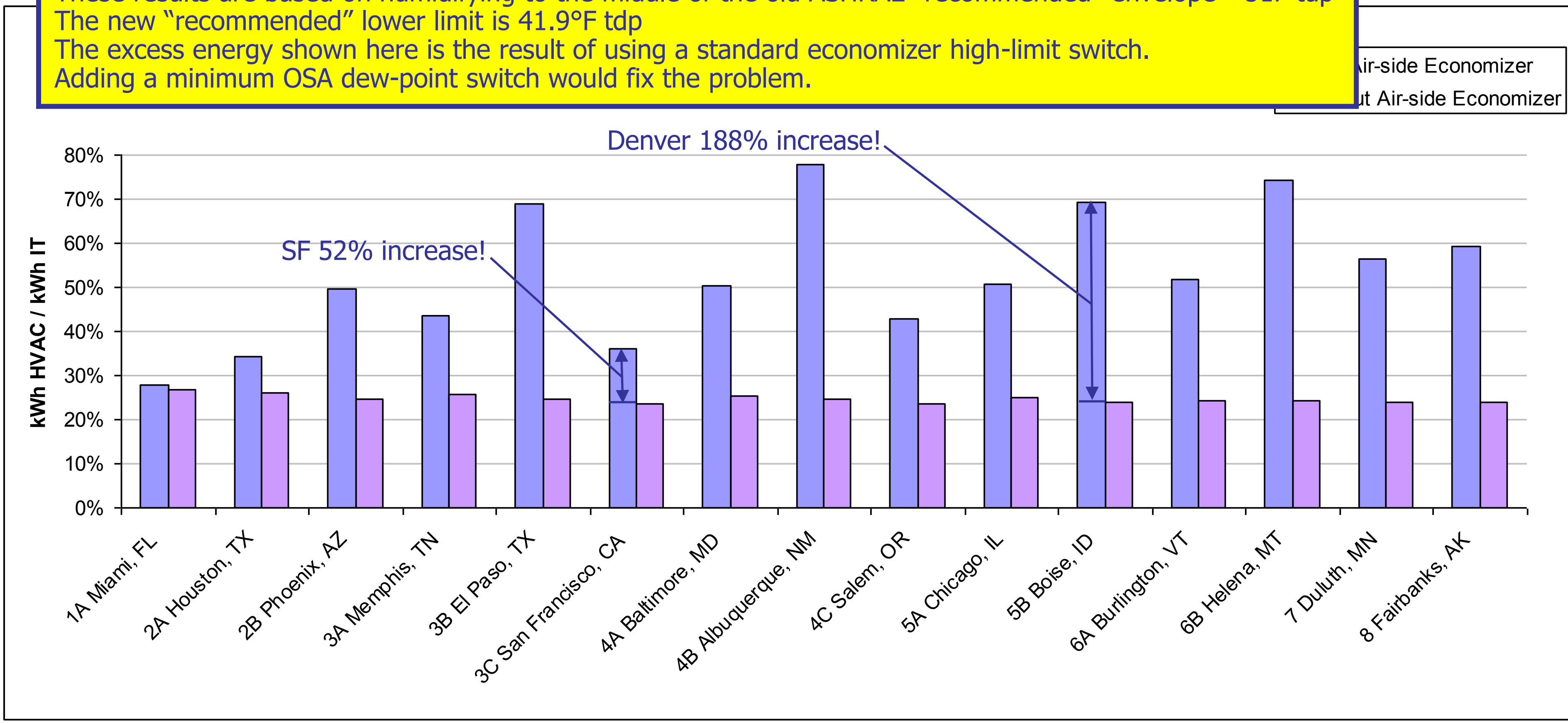
- Dampers
  - OSA
  - RA
- Temperature sensors
  - SAT
  - RAT
  - OAT
- High limit switch
- Minimum position control (ventilation)
- Space pressure control
  - Barometric or powered

Air-side economizer savings: no humidification and code minimum water-cooled chilled water plant

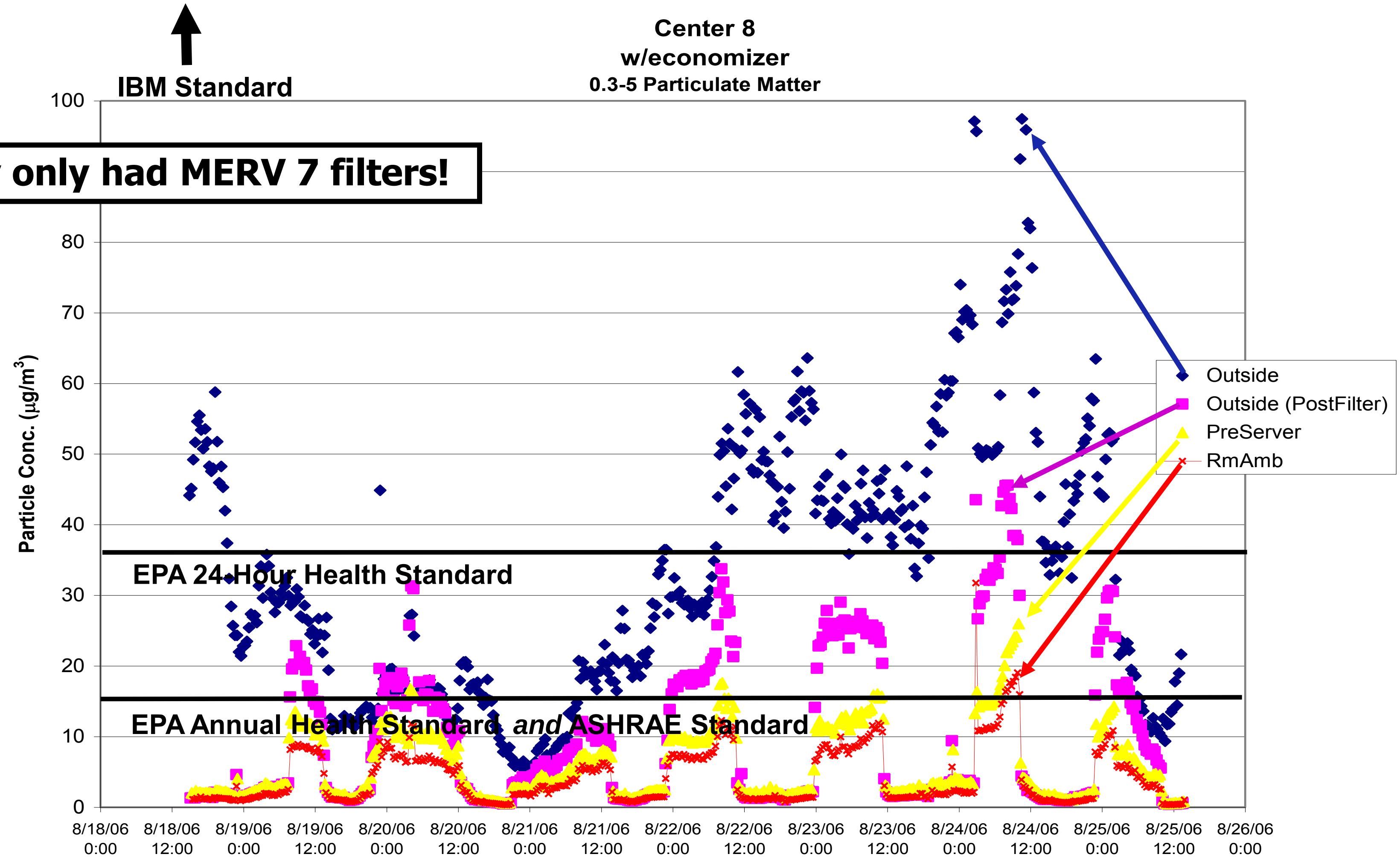


Air-side economizer savings? with humidification and code minimum water-cooled chilled water plant

These results are based on humidifying to the middle of the old ASHRAE “recommended” envelope ~51F tdp
The new “recommended” lower limit is 41.9°F tdp
The excess energy shown here is the result of using a standard economizer high-limit switch.
Adding a minimum OSA dew-point switch would fix the problem.



LBNL particulate study at data center w/economizer

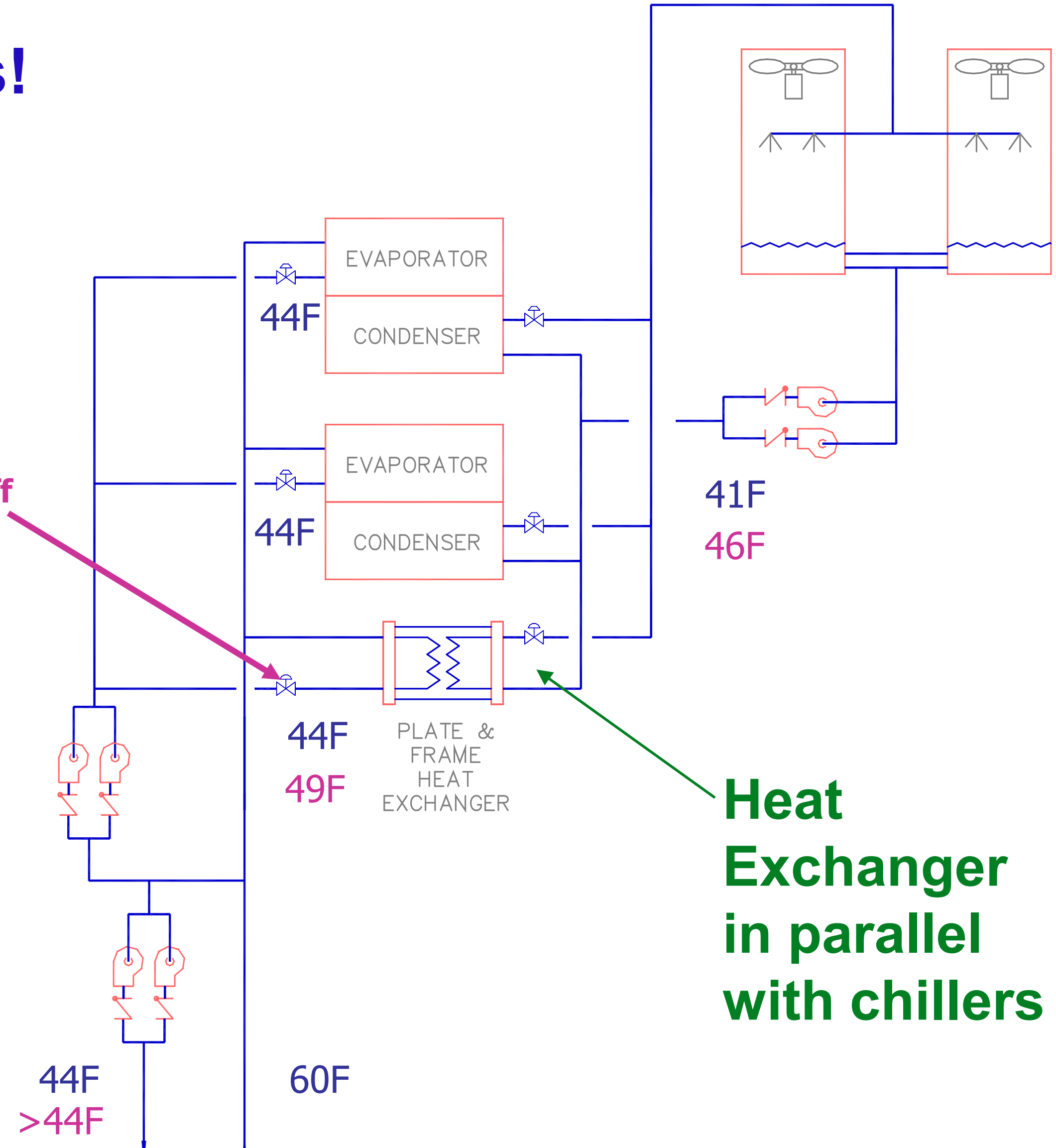


Air-side economizer summary

- Use differential temperature high limit switches in all but the most humid climates
- Can improve the reliability of the plant
- Generally improves indoor air quality
- Humidity control can negate savings
  - If used, lock out the economizers when the OSA is below the humidity control dewpoint temperature setpoint
- Particulates shouldn’t be an issue with good filtration (MERV 13 or higher)
- Work best with high return temperatures (aisle containment)
- Consider a direct evaporative stage to increase the hours of free cooling
- Consider controls to prevent smoke from outside being pulled into the data center (e.g. grass fire)

Non-integrated water-side economizer (WSE)

Don't do this!

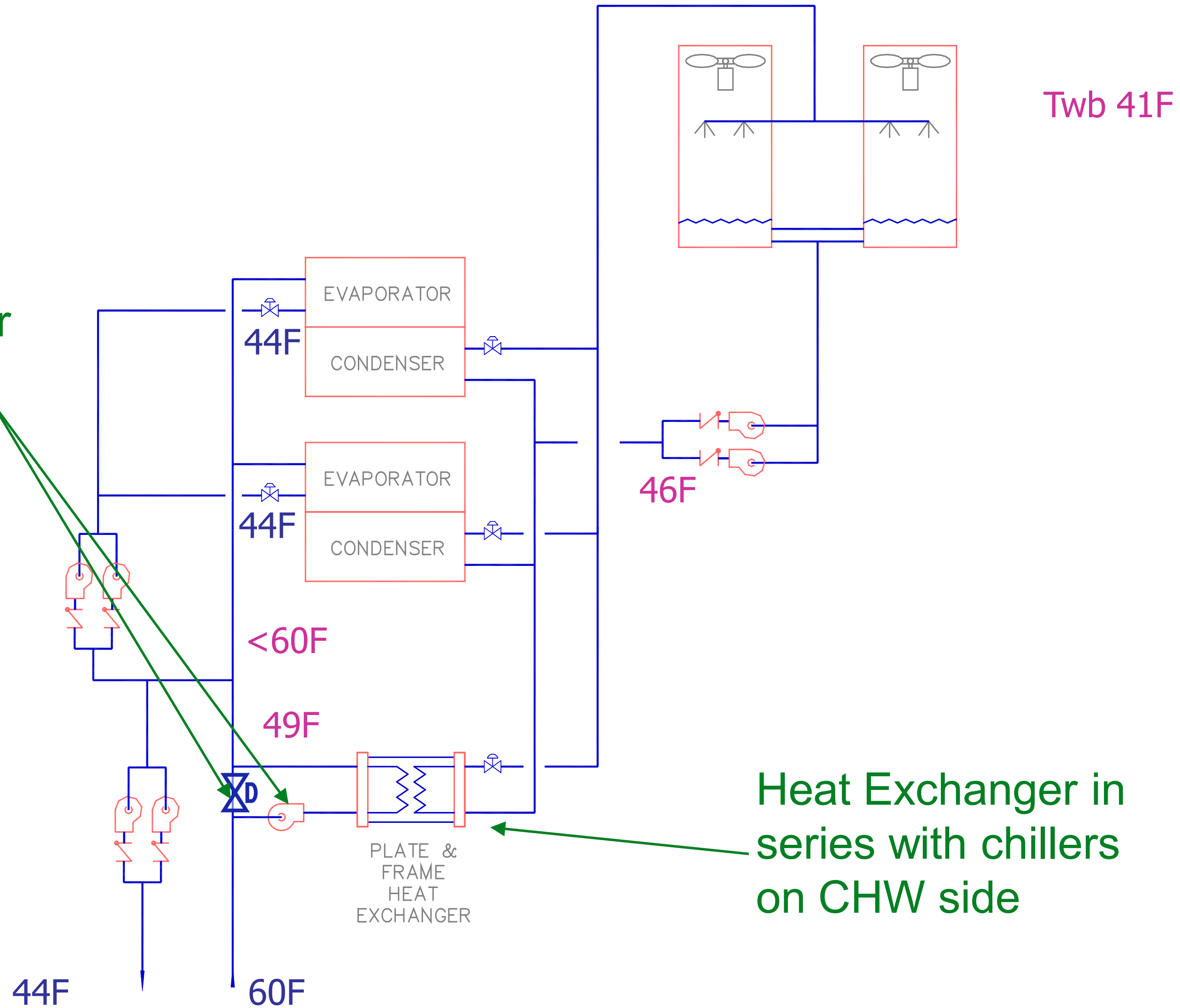


You have to shut off the economizer to satisfy the load!

Heat Exchanger in parallel with chillers

Integrated water-side economizer (WSE)

You can use either a control valve or pump

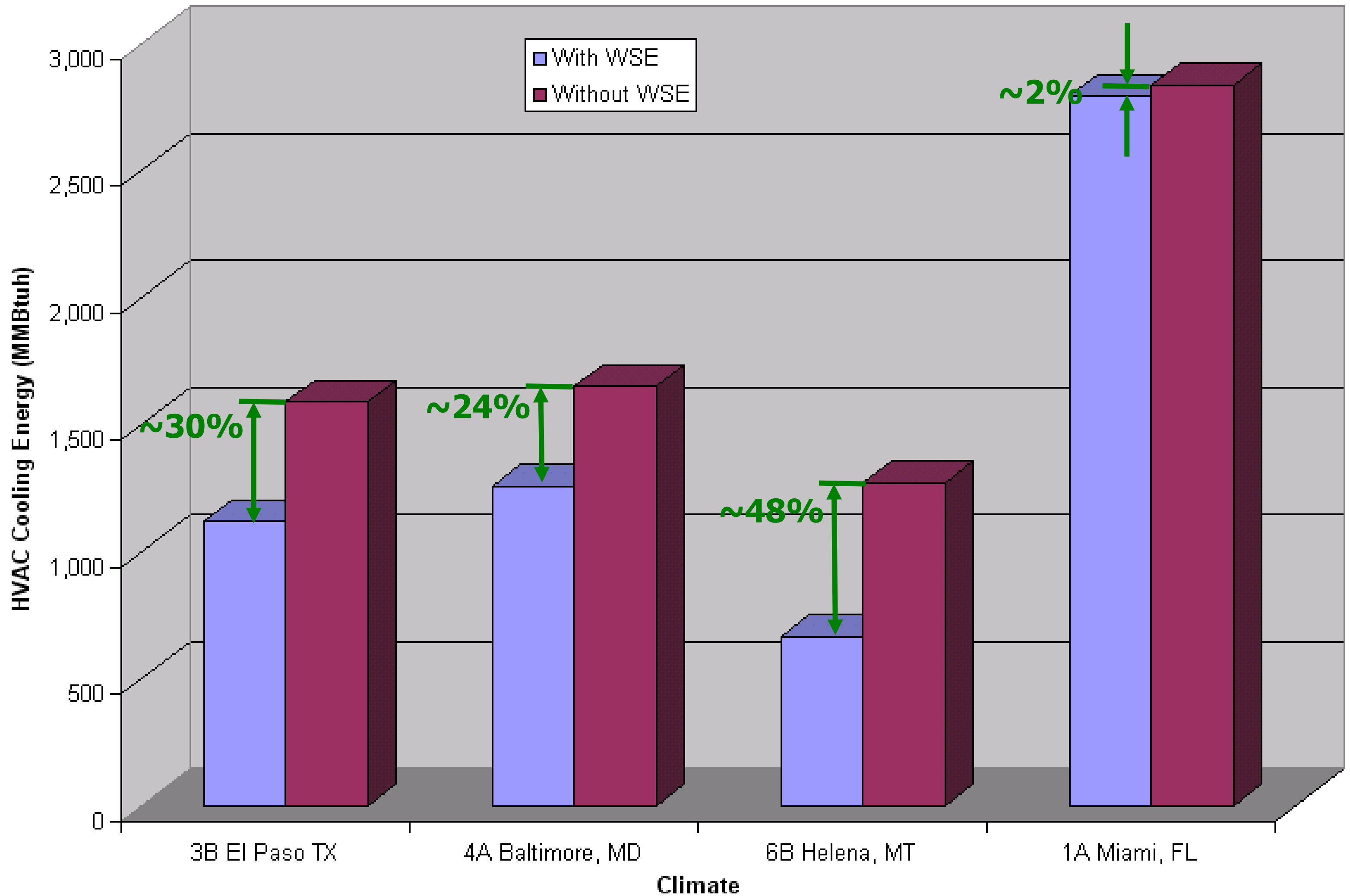


Heat Exchanger in series with chillers on CHW side

Example WSE Savings

- Example based on 200,000 sf office building with ~ 110 tons of data center load.
- Location Pleasanton CA (ASHRAE Climate 3B)
- (2) 315 ton chillers (630 tons total).
- Building has air-side economizer.
- Data center has CRAH units.
- Water-side economizer on central plant with HX (integrated, see previous slide)

Example WSE Savings



Implementing WSEs

- Put the HX on the plant CHW return line in series NOT in parallel with the chillers
- You need head pressure controls for chillers and other water-cooled equipment
- Works best with CHW reset (the warmer the better)
- Works best if you design coils for high Delta-T
- Consider oversizing towers
- Design towers for low flow

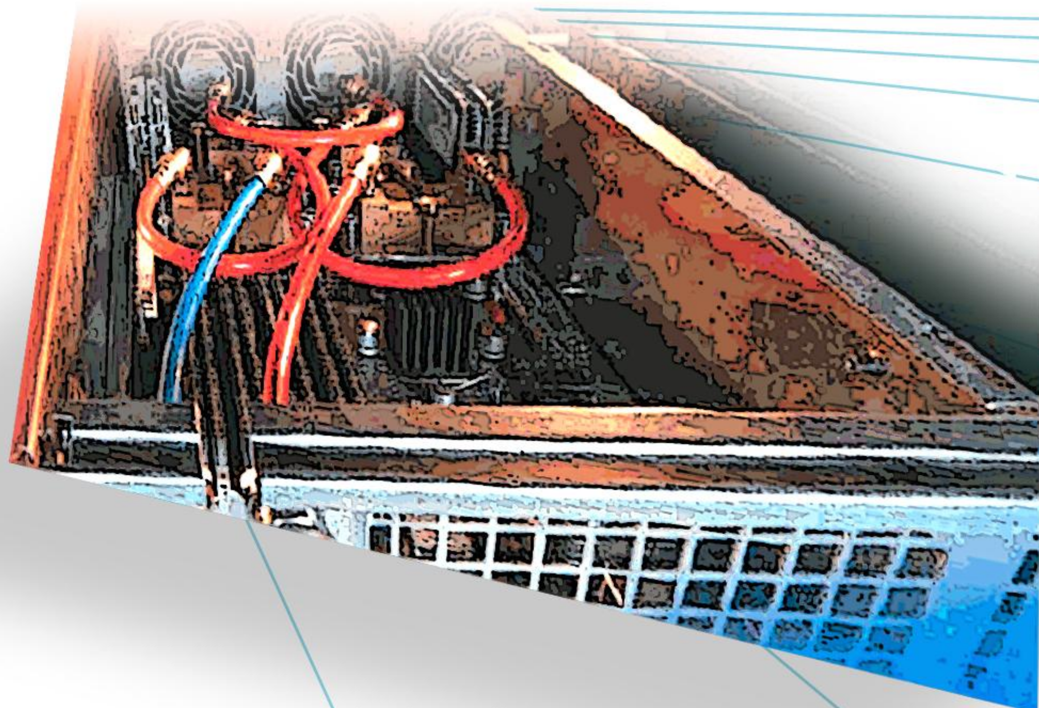
Non-energy advantages of WSEs

- Redundancy
- Limited ride-through if chillers trip
- Utilizes redundant towers

Free cooling take aways

- Air- and water economizers can save significant energy if properly designed and controlled.
- Air- economizers can increase energy usage if you have humidity controls.
- Air-economizers do increase particulates but these can be addressed with standard filtration.
- Water economizers should be integrated by installing free cooling heat exchanger in series with the chillers.

Lunch



Liquid Cooling Systems

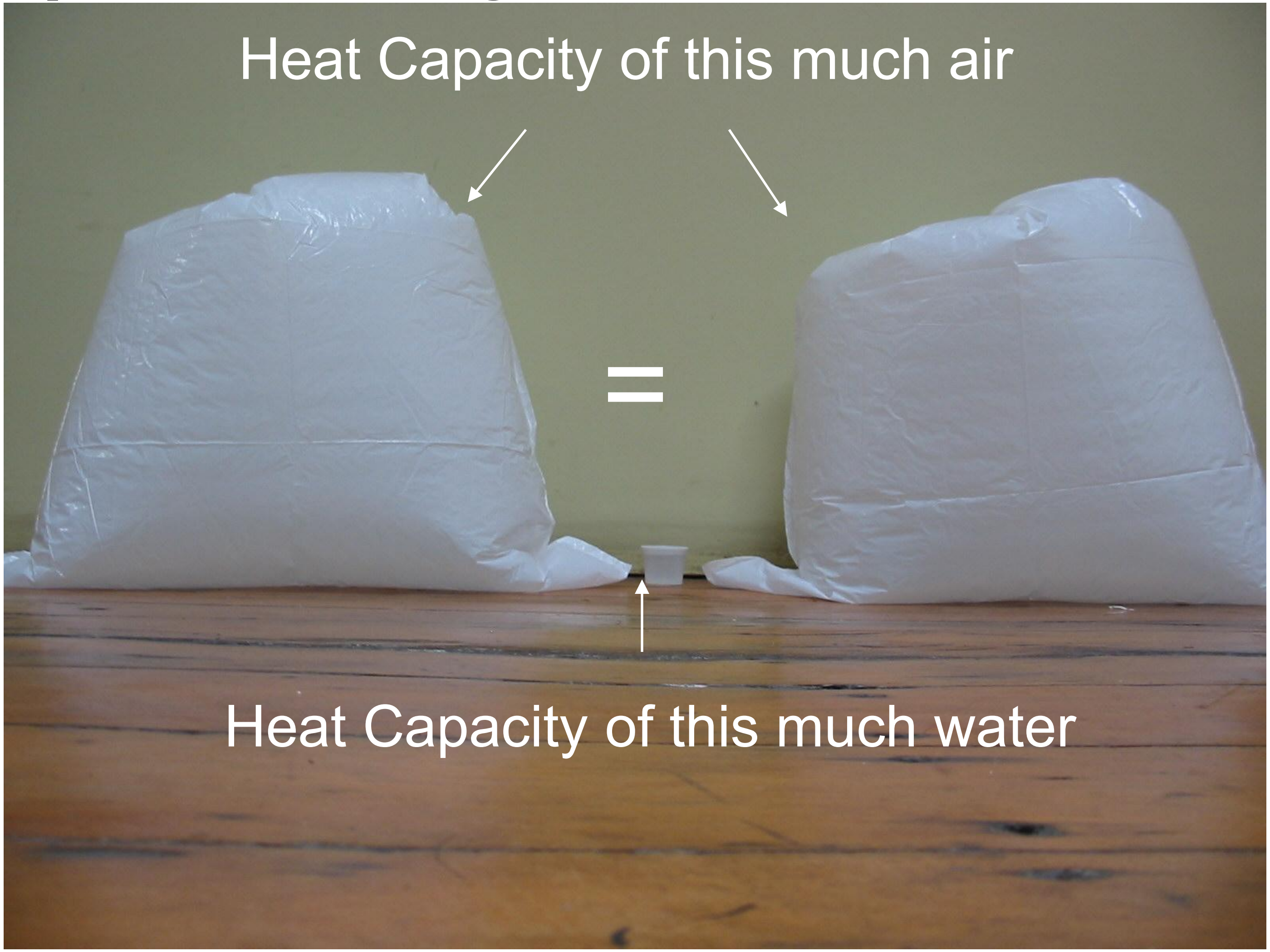
Mark Hydeman, P.E., FASHRAE

Taylor Engineering

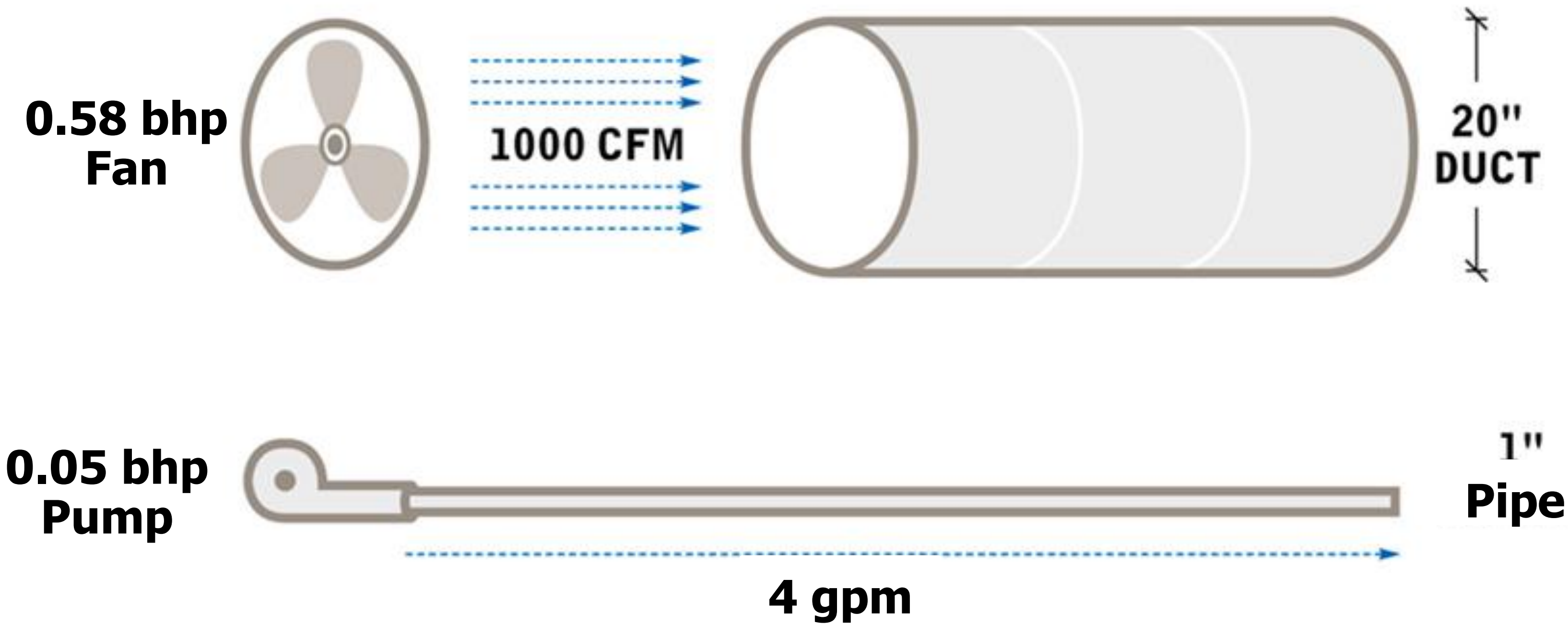
Outline

- Why liquid cool
- Liquid cooling options
  - Rack and row cooling
  - On board cooling
- Energy Benefits
- Interface with free cooling

Why Liquid Cooling?



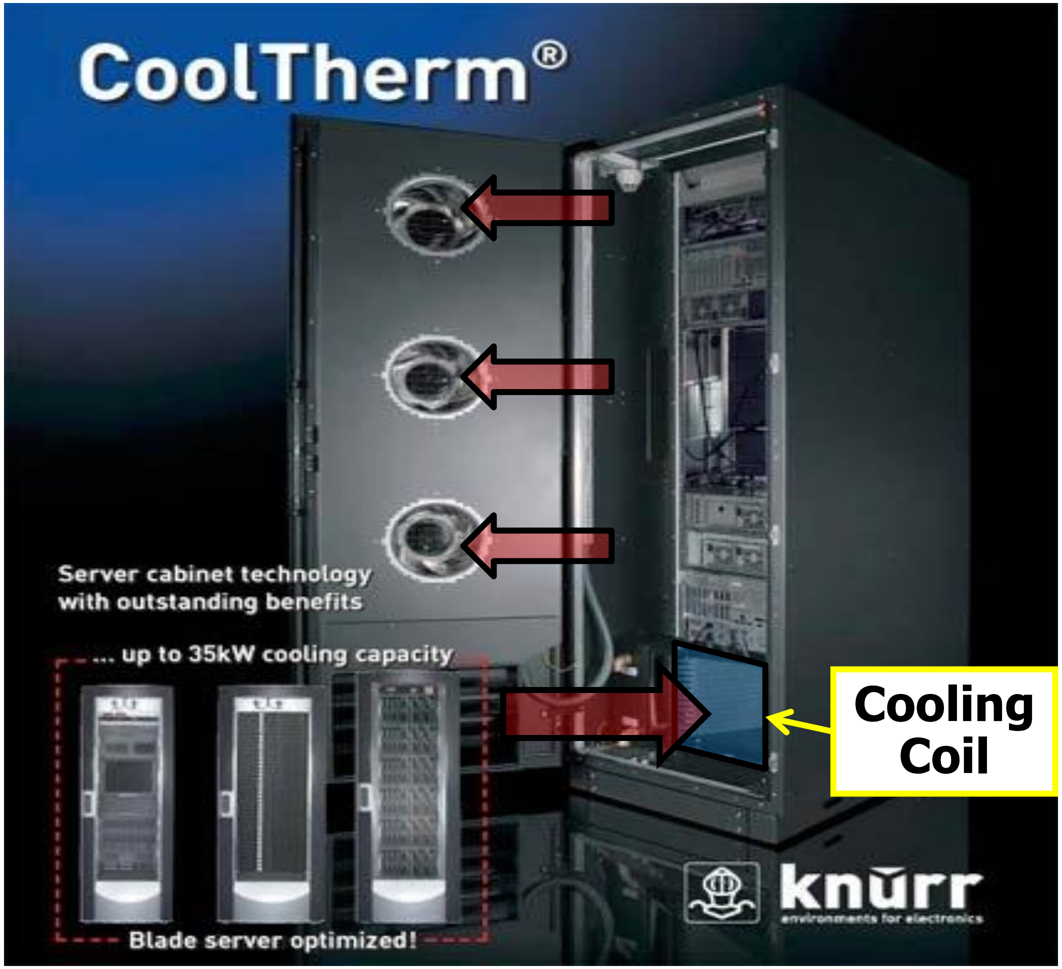
Fans move energy less efficiently



Flow		Formula	DT		BTUH	Eff	DP		Formula	BHP
1,000	cfm	BTUH=1.1*cfm*DT	21.8	°F	24,000	54%	2	in w.c.	bhp=cfm*DP/(6350*eff)	0.58
4	gpm	BTUH=500*gpm*DT	12.0	°F	24,000	80%	40	ft w.c.	bhp=gpm*DP/(3960*eff)	0.05

In rack liquid cooling

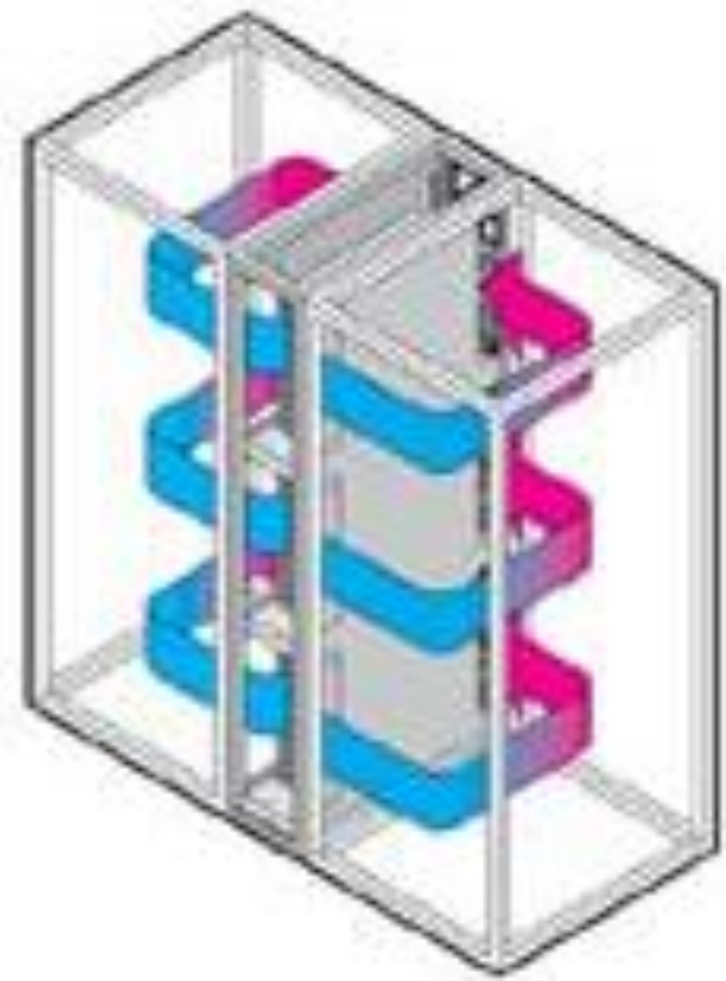
- Racks with integral coils and full containment



Rear door cooling

- Passive technology
- Relies on server fans for airflow
- Can use chilled or CW for cooling

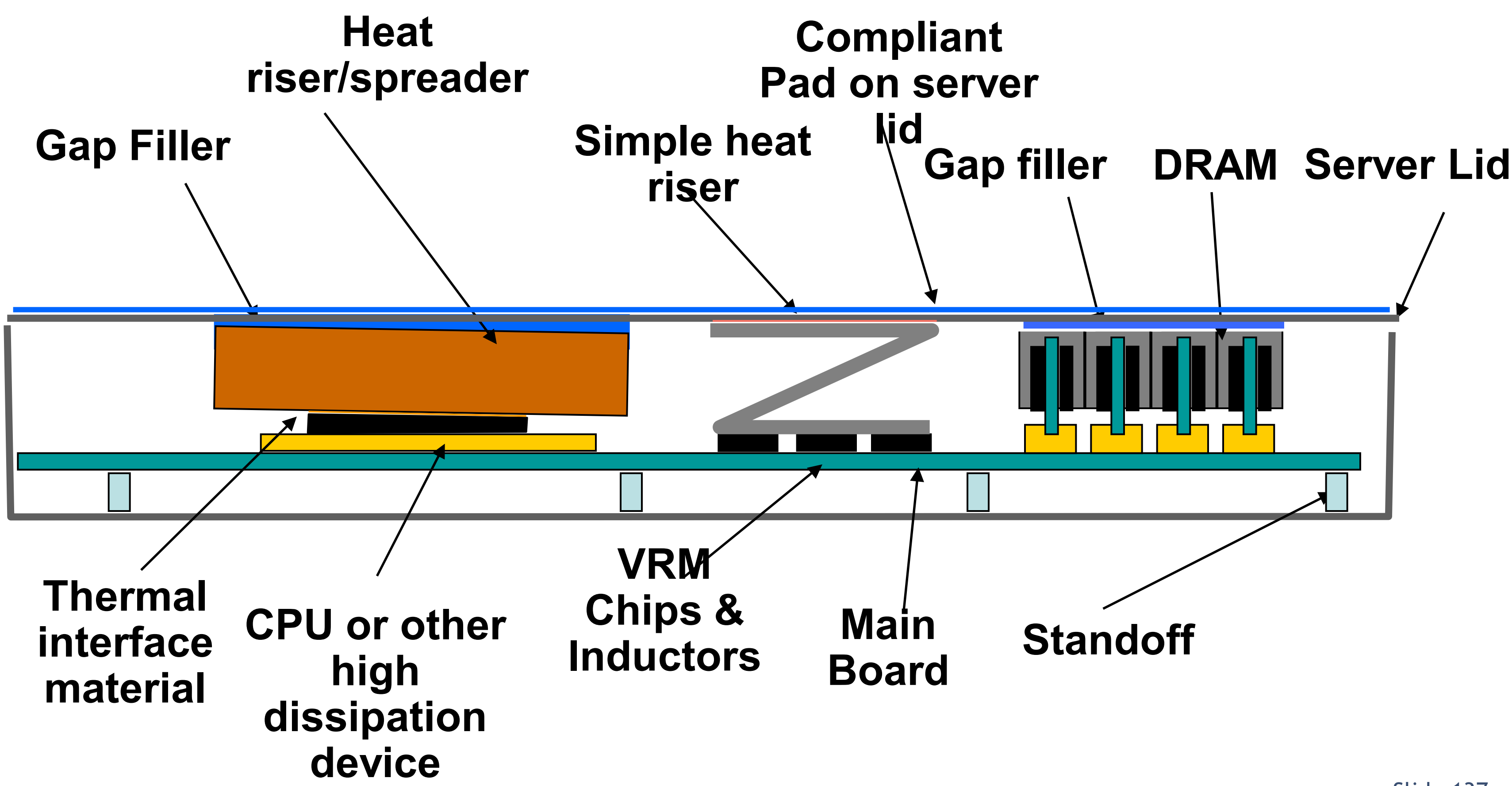
In row cooling



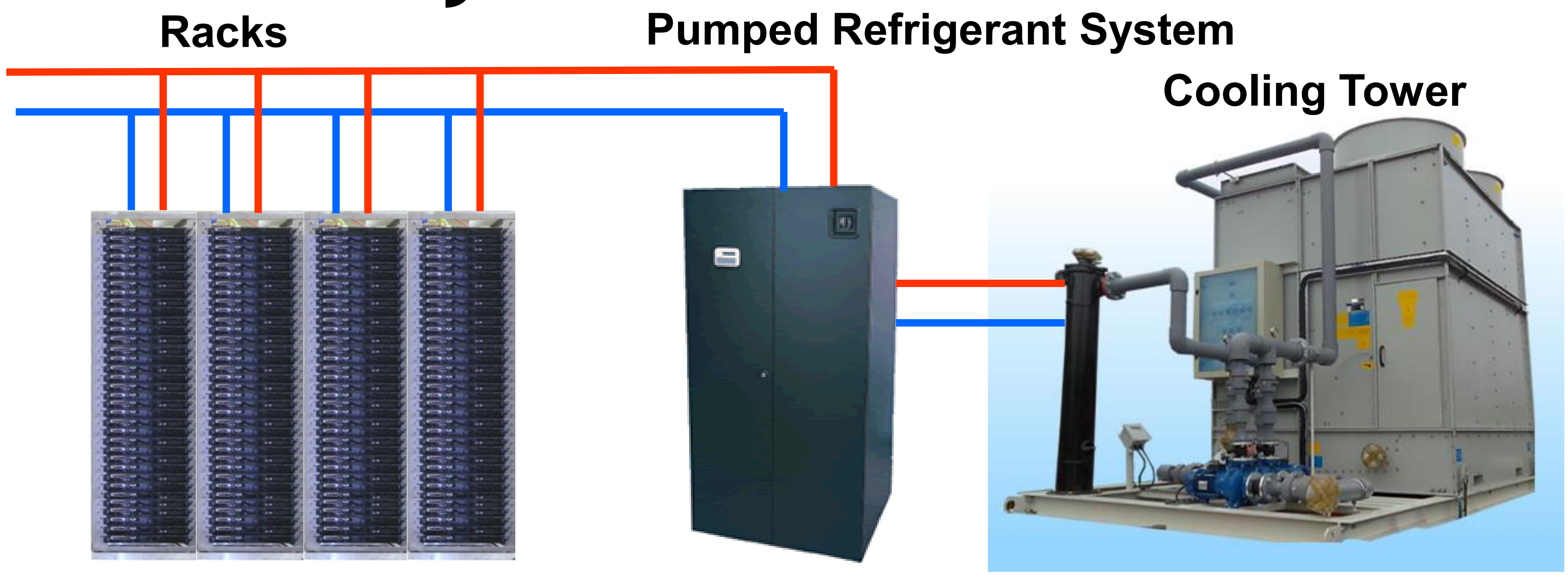
On board cooling

Liquid Cooling "Clustered Systems"

- Server fan is removed
- Heat risers connect to top plate which has a microchannel heat exchanger



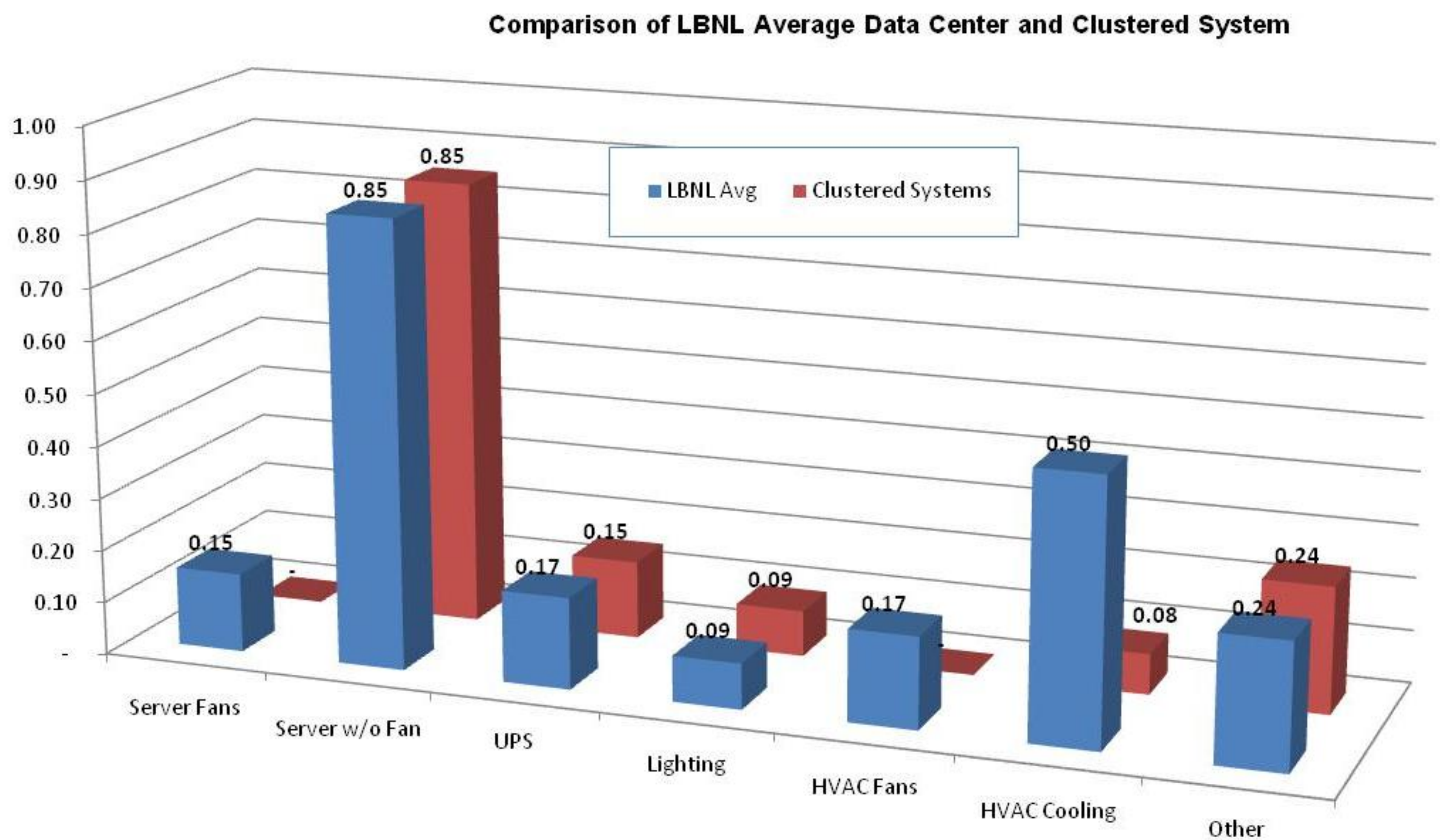
Clustered Systems Architecture



- Simple installation
- Standard interfaces
- Highly scalable

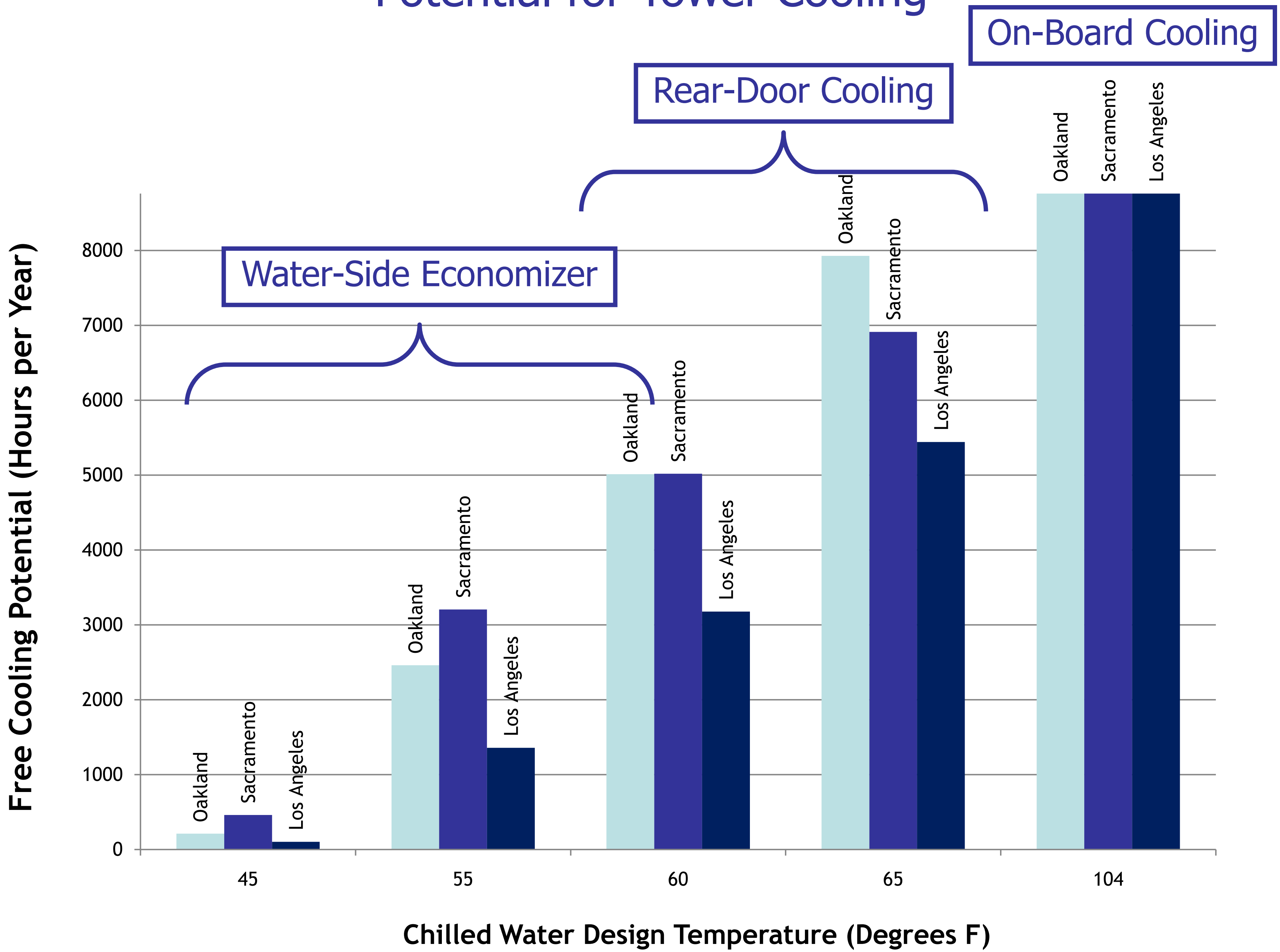
- Simple loop control systems
- Integrable with enterprise management tools

Savings

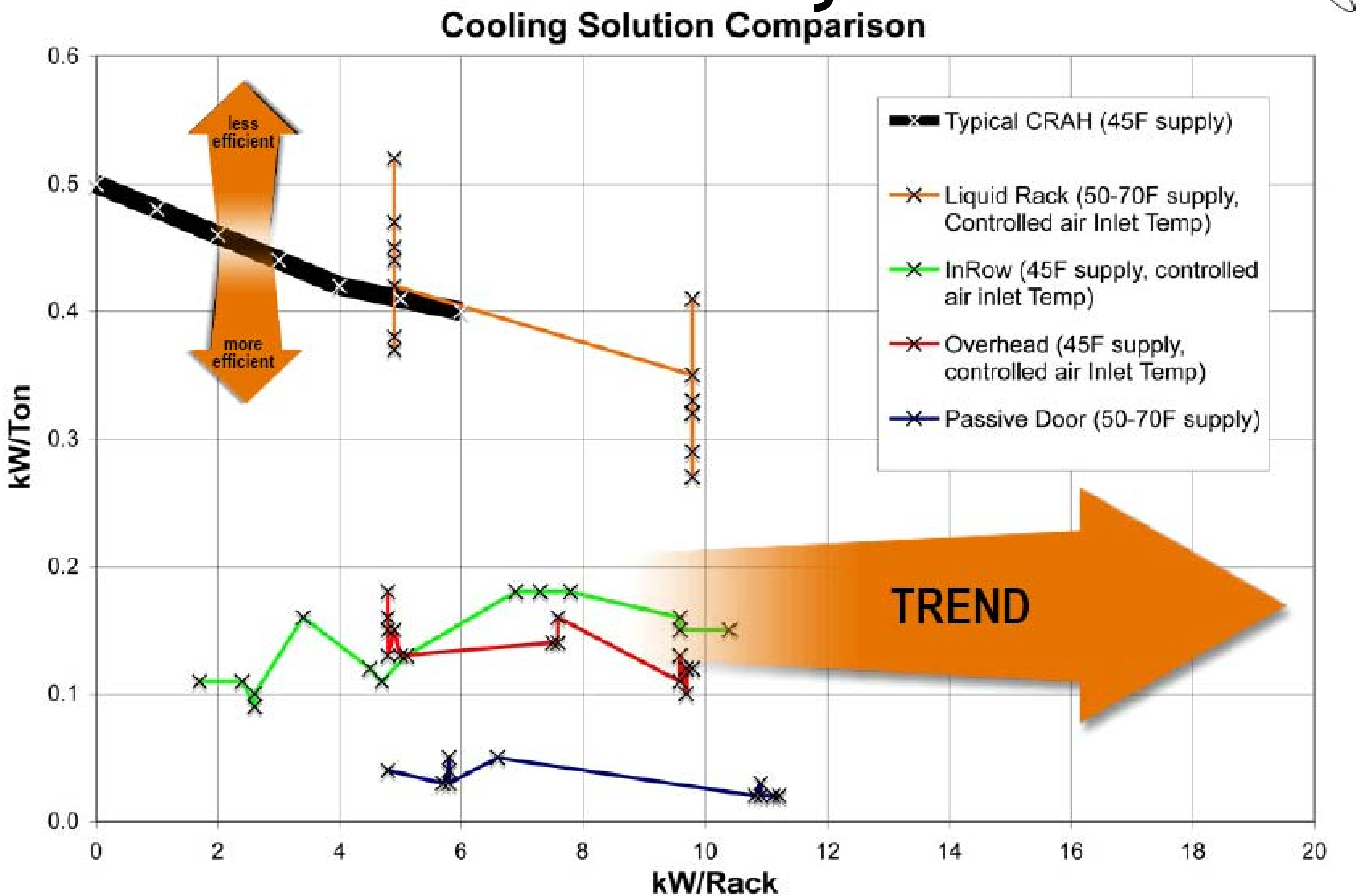


Comparison of LBNL Average Data Center and Clustered System
LBNL Avg
Clustered Systems
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
-
0.15
-
0.85
0.85
0.17
0.15
0.09
0.09
0.17
-
0.50
0.08
0.24
0.24
Server Fans
Server w/o Fan
UPS
Lighting
HVAC Fans
HVAC Cooling
Other

Potential for Tower Cooling

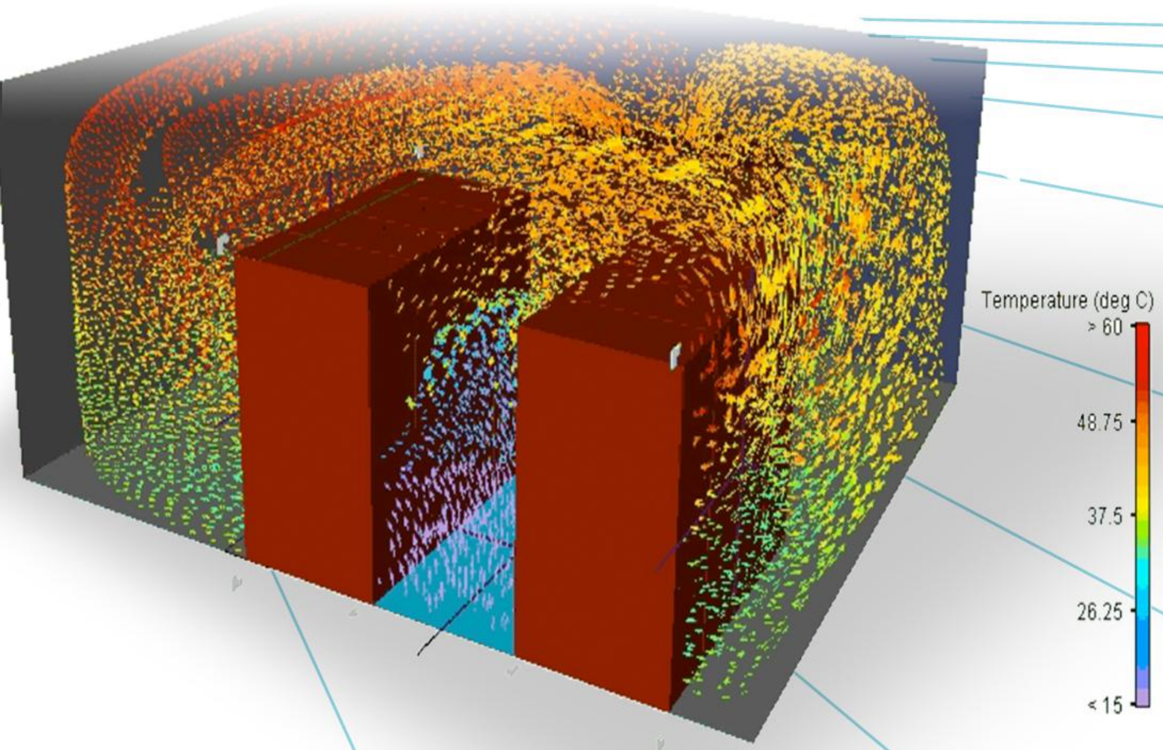


Sun Chill Off Preliminary Results



Liquid cooling take aways

- Liquid has greater heat removal capacity
- Pumps use less energy than fans
- Coupling heat removal to the source eliminates mixing
- A wide variety of commercially available liquid solutions are available
- The potential for energy savings is large
- Redundancy is a challenge for some liquid cooling technologies
- Water side free cooling can provide cooling with reduced chiller operation for much of the year



Data Center Retrofit Opportunities

Mark Hydeman, P.E., FASHRAE

Taylor Engineering

Retrofit opportunities

- Air management
- Water-side economizer
- VAV conversion of fans
- Control upgrades
- Liquid cooling (particularly for high density racks)

Air Management

- Plug holes in racks
- Plug holes in floor (if underfloor)
- Remove unused cable (underfloor obstructions)
- Add partitions for containment
- Rebalancing tiles
- Converting CRACs/CRAHs to VAV

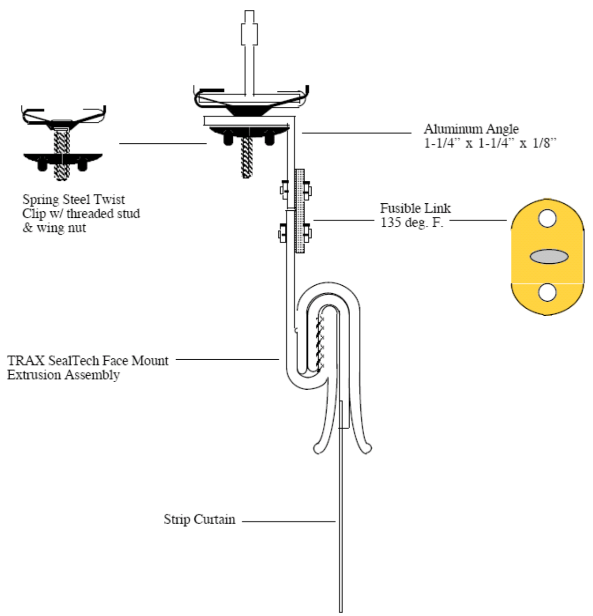
Plugging holes

Koldlok Cable Management

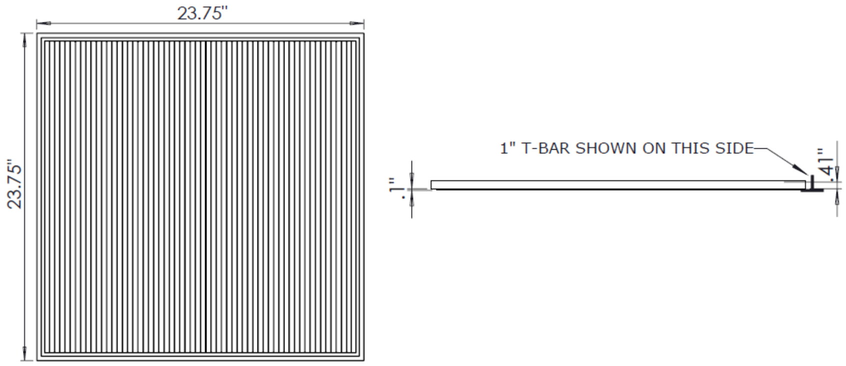
PlenaForm Baffle System

Partitions

CoolShield or Trax SealTech

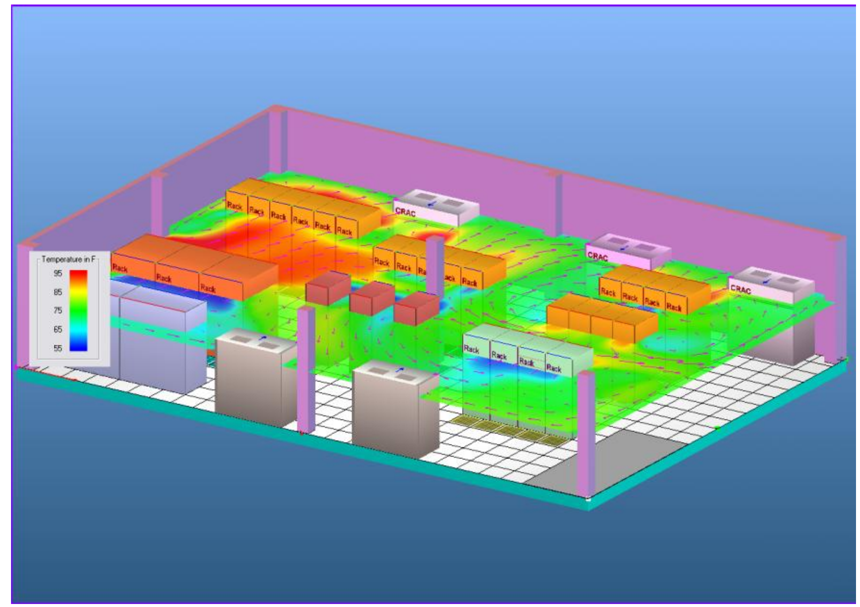


Ceilume Heat Shrink Tiles



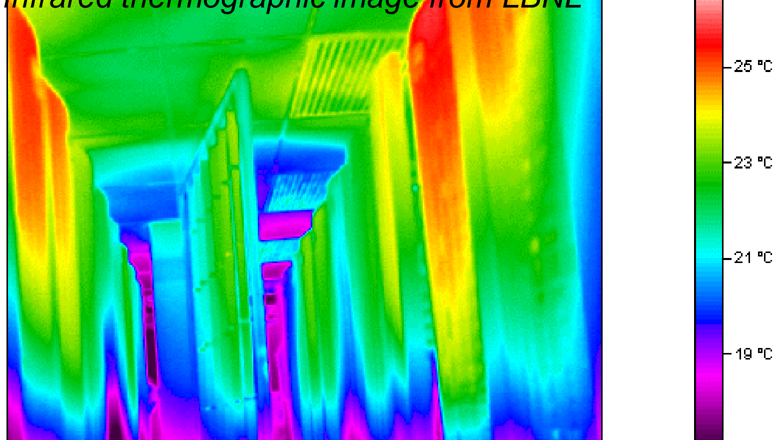
How do you balance airflow?

- Spreadsheet
- CFD
- Monitoring, infrared thermography or other site measurements
- Using aisle containment
- Live imaging systems



CFD image from TileFlow http://www.inres.com/Products/TileFlow/tileflow.html, Used with permission from Innovative Research, Inc.

Infrared thermographic image from LBNL



SynapSense Wireless Sensor Network

- Wireless sensor network
- “Self-organizing” nodes
- 802.15.4 (not 802.11)
- Multi-hop routing
- Non-invasive installation
- 2 internal & 6 external sensors per node
- Can measure temp., humidity, pressure, current, liquid flow, liquid presence & particle count.
- Approximately \$90/point installed (10%-20% of standard DDC costs)

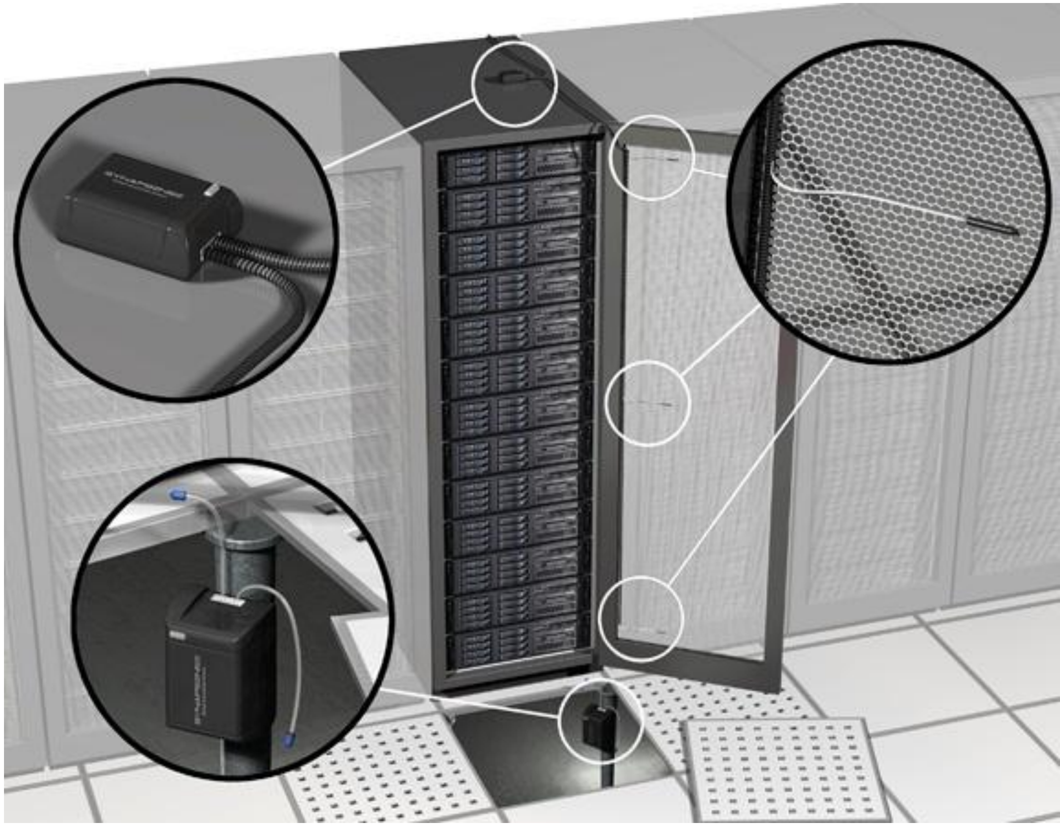
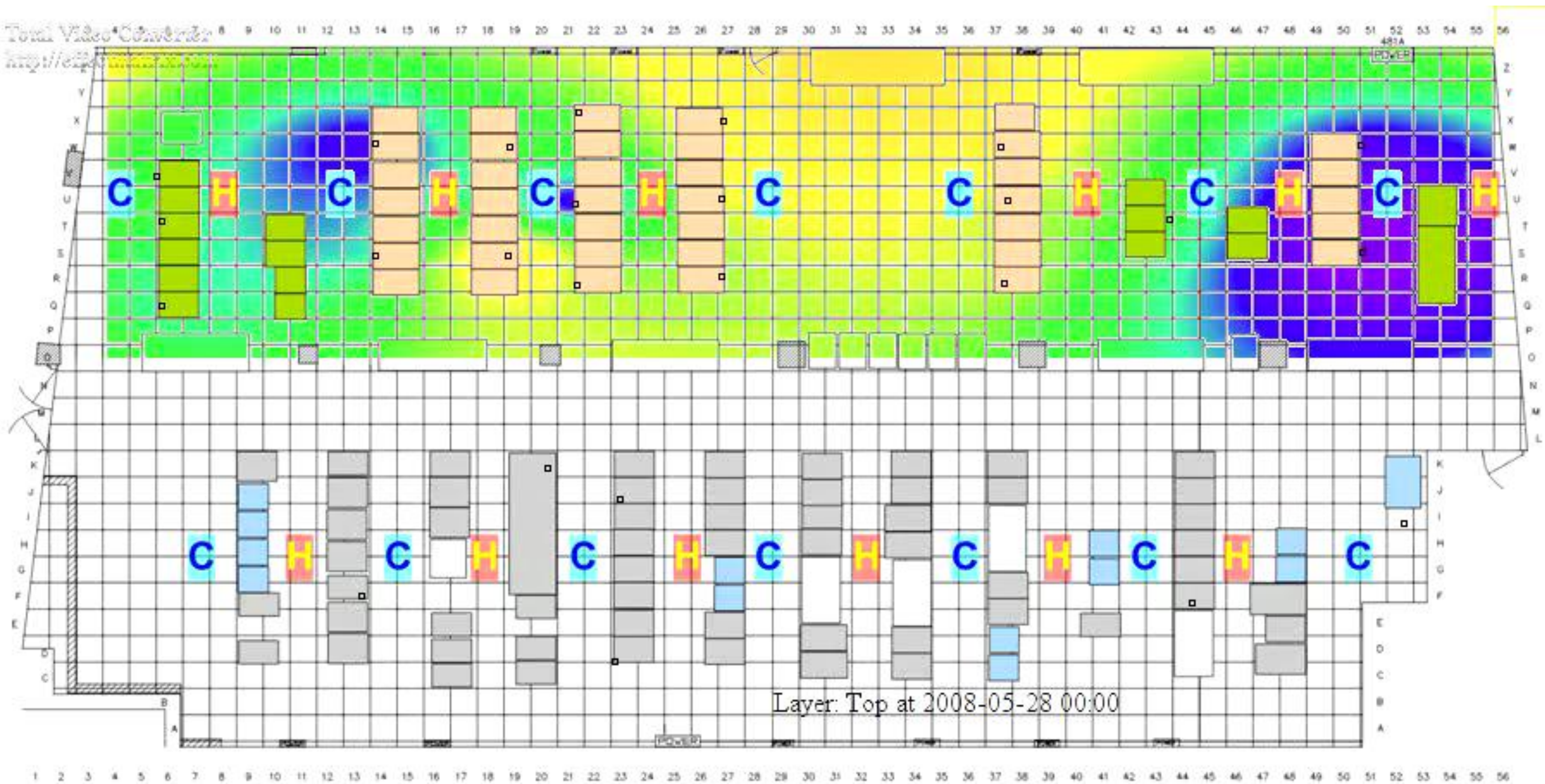
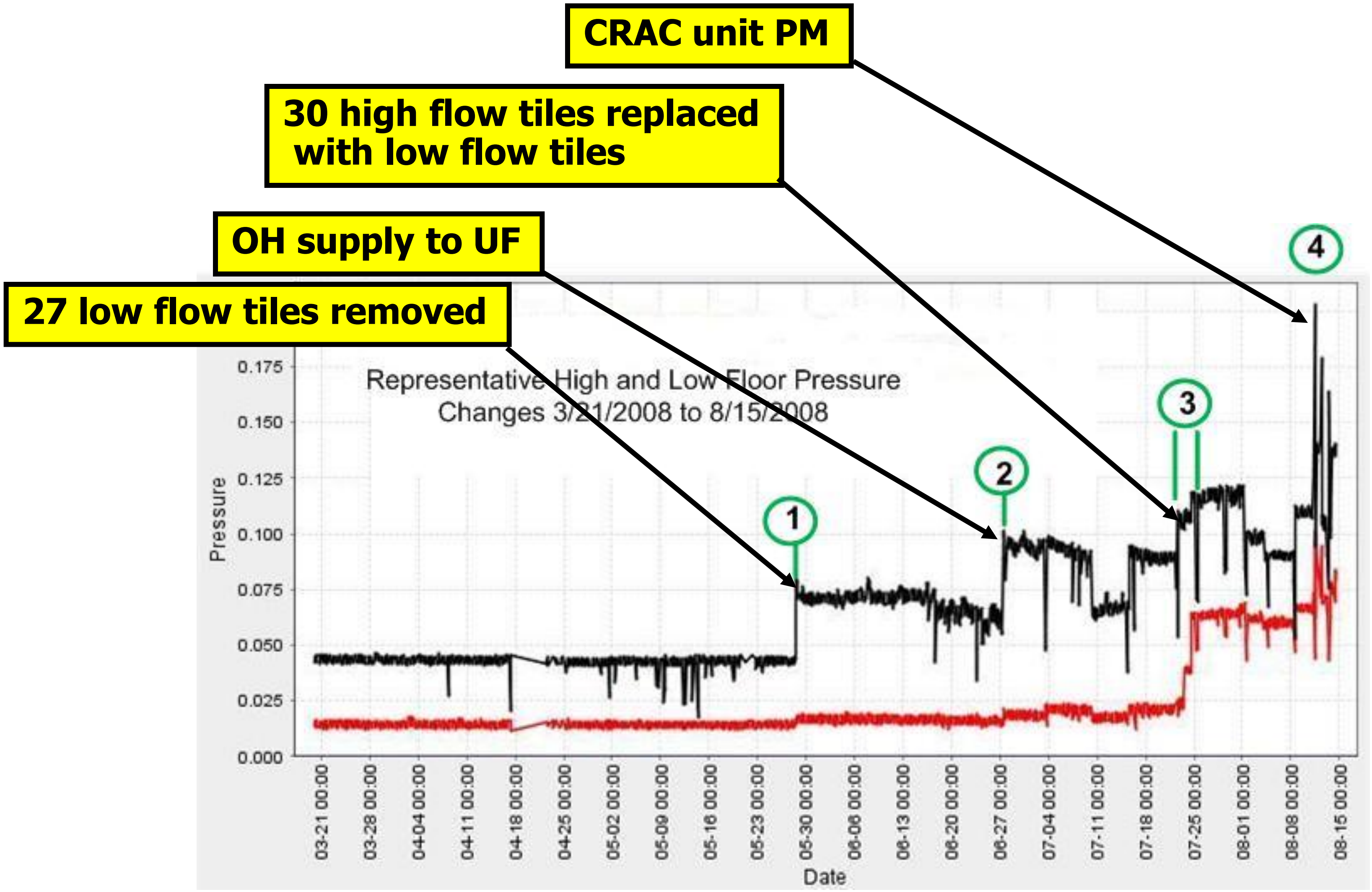


Image: SynapSense

SynapSense ‘LiveImaging’



Case study at LBNL 50B-1275



1275 case study results (so far)

- 7% increase (~30kW) in IT load with 8% less fan energy
- CRAC unit setpoints 3°F warmer
- Fewer hot spots
- (1) 15 ton unit turned off
- (1) extra 15 ton unit on-line but redundant
- The wireless sensor network enabled facilities to visualize, track and fine tune many changes in the data center including tuning of the floor tiles

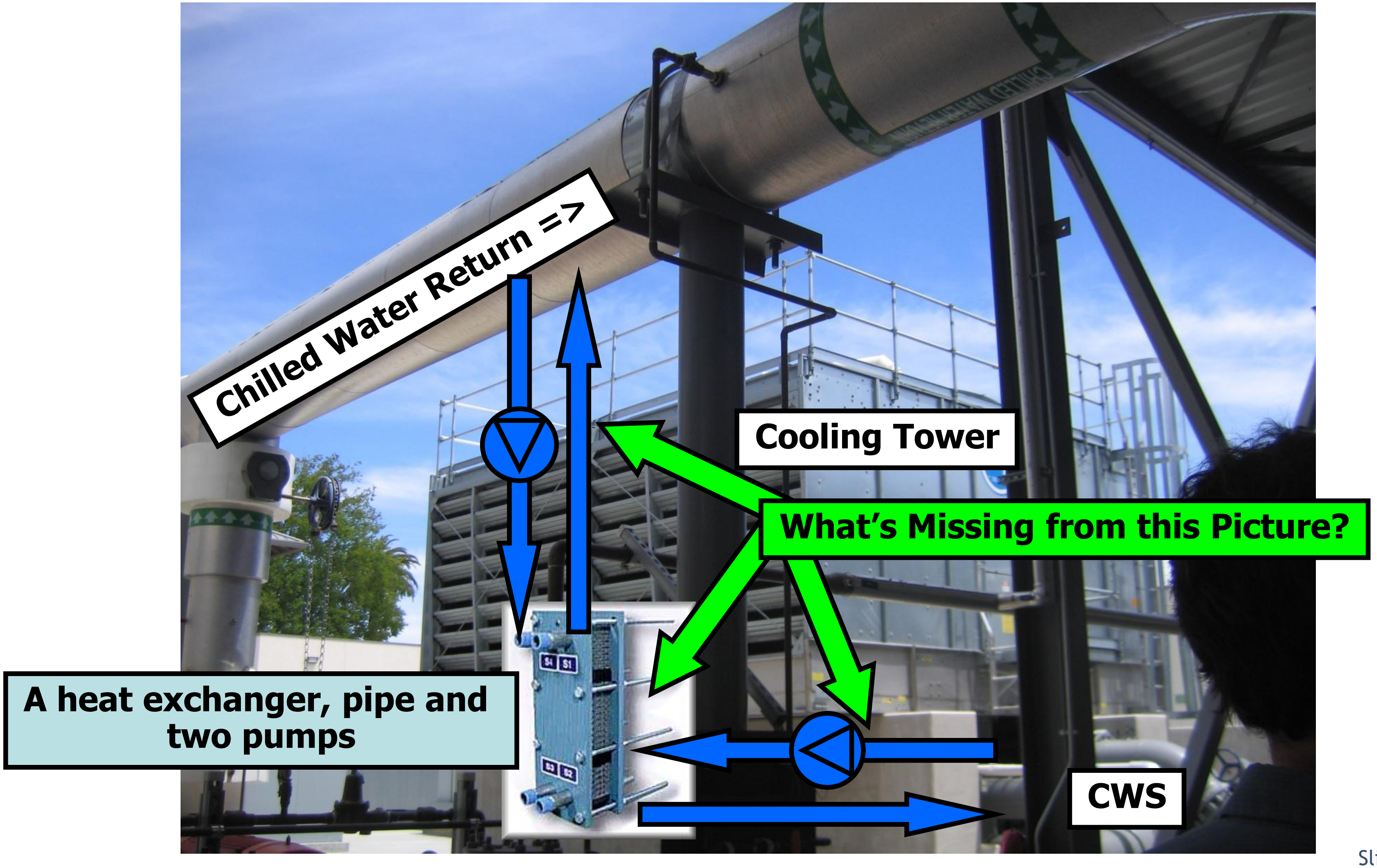
Other wireless sensor resources

- Standard EMCS vendors (e.g. ALC and Siemens)
- Federspiel Controls http://www.federspielcontrols.com/
- Arch Rock http://www.archrock.com/

Water side economizer retrofits

- For data centers with water-cooled chilled water plants.
- Can be installed live using hot-taps.
- Will need space for HX and possibly pumps.
- Need to provide head pressure control for chillers (to prevent low refrigerant or oil pressure trips).
- Make sure to install as “integrated”.
- Can convert non-integrated economizers if space allows.

Water-Side Economizer Retrofit



Converting Air Systems to VAV

- Large potential energy savings
  - Fans energy is as much as ½ of HVAC energy
  - 60% to 80% of the fan energy is internal to CRAH unit
  - Redundant units can be run in parallel
- Difficult with DX units (air or water cooled)
  - Must protect the coil from freezing
  - SynapSense and Federspiel Controls are both working on this
- Easy with chilled water units

Conversion of CRAC/CRAH Units to VAV

Retrofit Costs		
Cost	$ 211,000	Drives
	$ 693,000	Controls
	$ 904,000	Total
Units	62	
Calculations Per Unit Retrofit		
Cost/unit	$ 14,581	
BHP	11.4	bhp
Energy	8.5	kW
Post Retrofit Speed	85%	
New BHP	7.0	bhp
Energy	5.2	kW
Savings	3.3	kW
Annual	$ 3,457	$/yr
Simple Payback	4.2	years
Present worth of the savings	***$ 36,125***	Per unit
Net present worth of the project	***$ 21,544***	Per unit
PWF Assumptions		
$/kwh	$ 0.12	$/kWh
discount rate	7%	
electricity escalation rate	2%	
study period (yrs)	15	
effective discount rate	4.9%	
NPV multiplier	10.45	
PW Energy Cost	$ 2,239,751.73	
LCC Savings	$ 1,335,751.73	

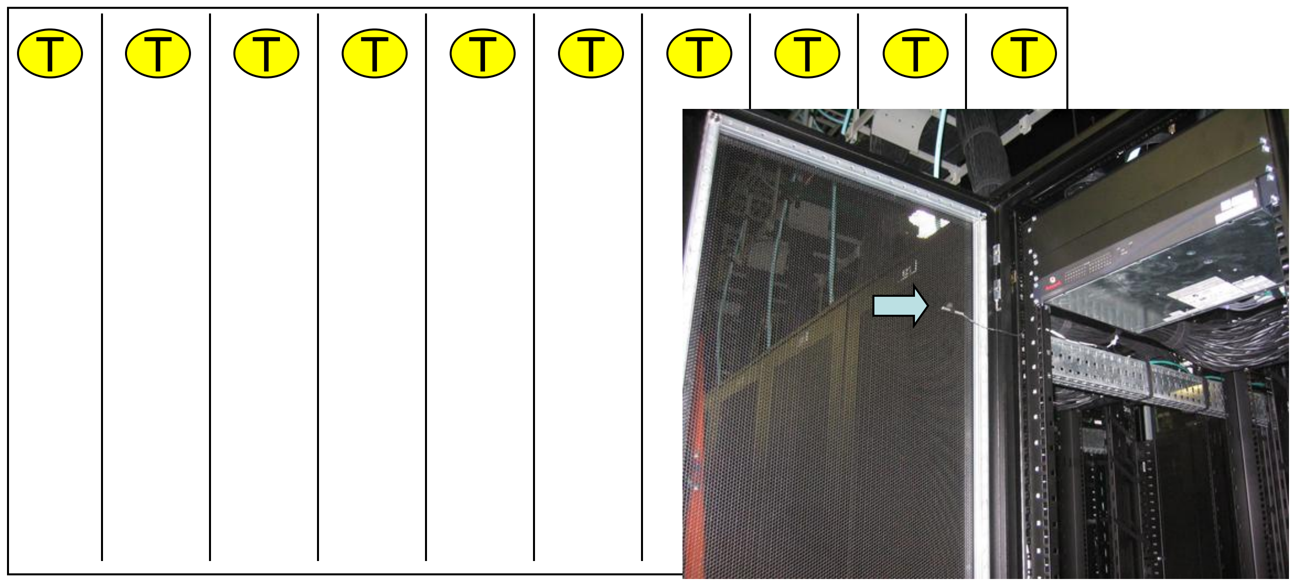
Temperature control

- Design Conditions
  - Maintain inlet conditions at servers between 64°F and 80°F.
    - 59°F to 90°F allowable.
    - At ~77°F two speed and variable speed server fans speed up (using more IT fan energy).
- Best practice
  - Provide feedback from racks.
    - Hardwired or wireless EMCS sensors.
    - Network data exchange with server on-board sensors.
  - Reset supply temperatures upward to keep most demanding rack satisfied (but below 77F).
  - Can have local temperature zones with distributed CRAC/CRAH/AH units.

Rack temperatures with UF supply

1. Reset SAT to keep rack EATs within design range

2. Keep SAT above minimum for design



Elevation at a cold aisle looking at racks

Wired sensors shown.

Wireless options are now readily available.

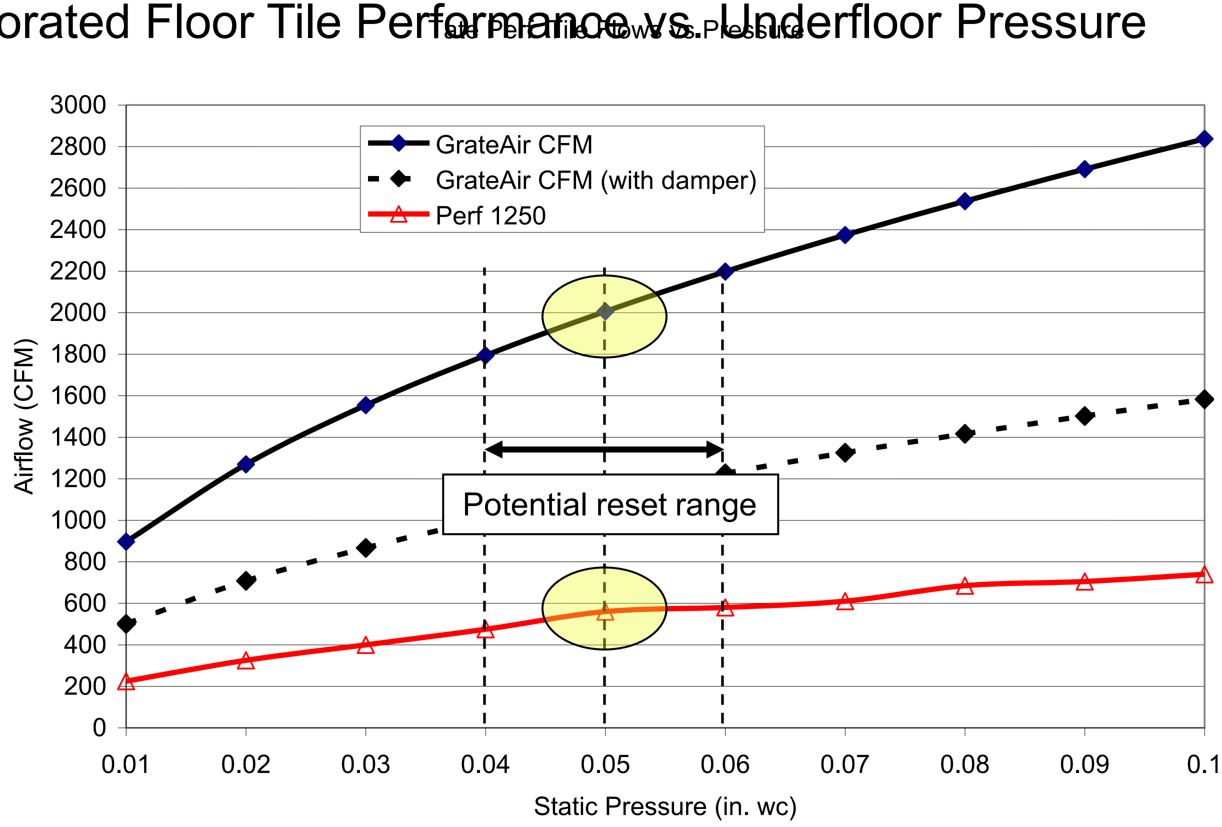
Communication with the servers is in development (LBNL demonstration).

Airflow controls underfloor

- All supply fans controlled to same speed.
- Reset fan speed and supply temperature by highest rack temperature (slow acting loop).
- Group racks by areas of influence (see following slides)

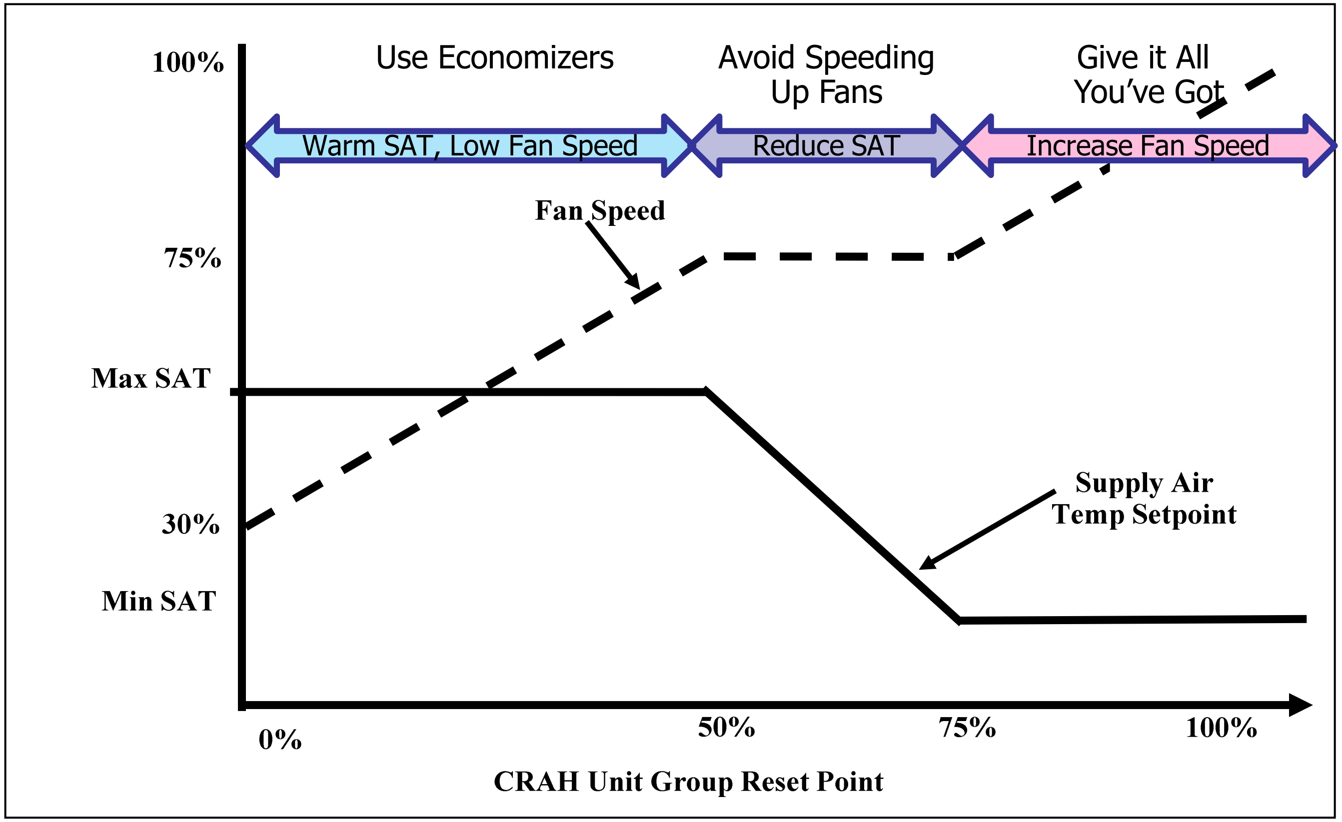
Reset of floor pressure to satisfy racks

Tate Perforated Floor Tile Performance vs. Underfloor Pressure



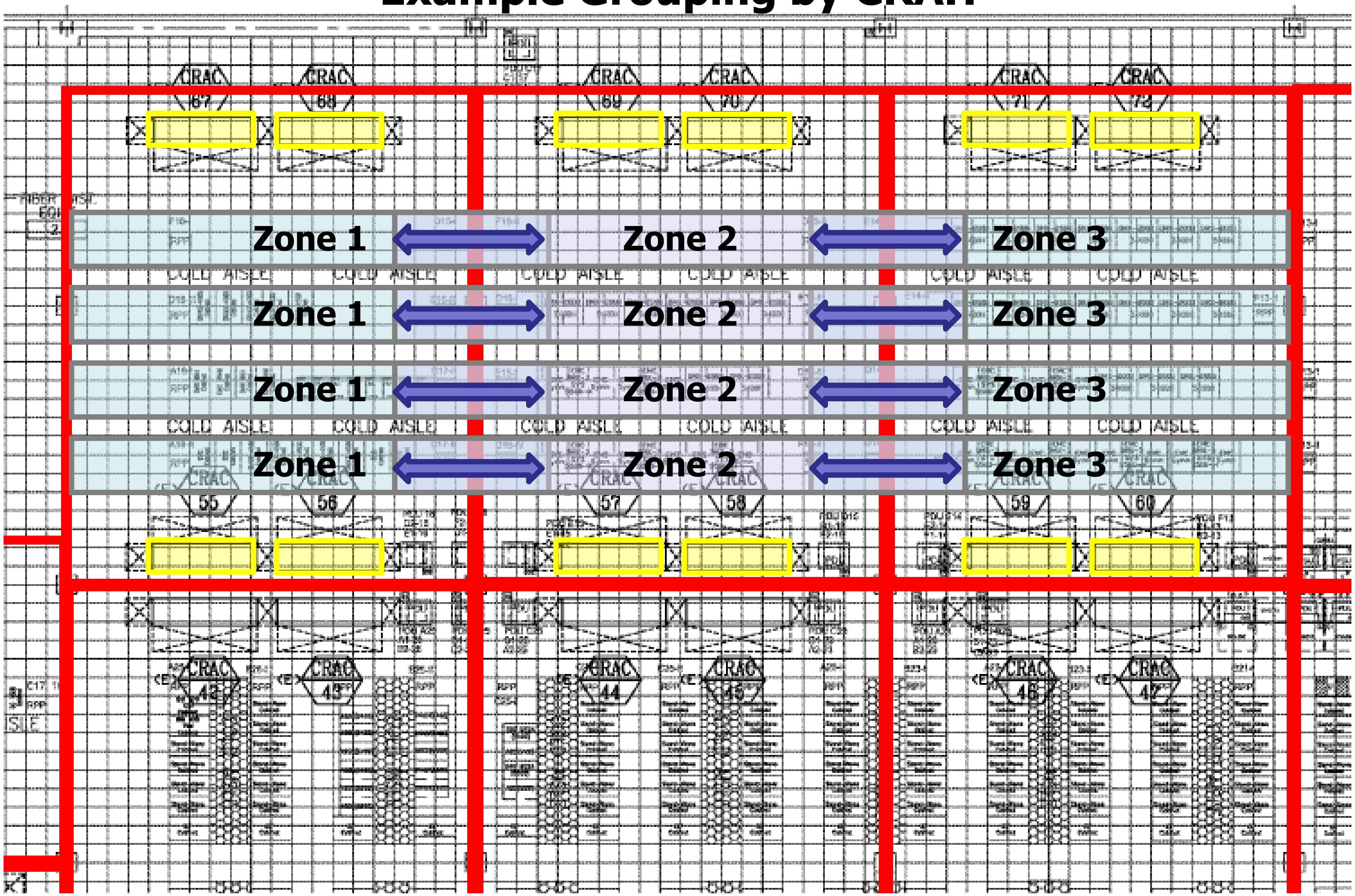
Temperature and Airflow Control

Reset controls by CRAH Group



Temperature and Airflow Control

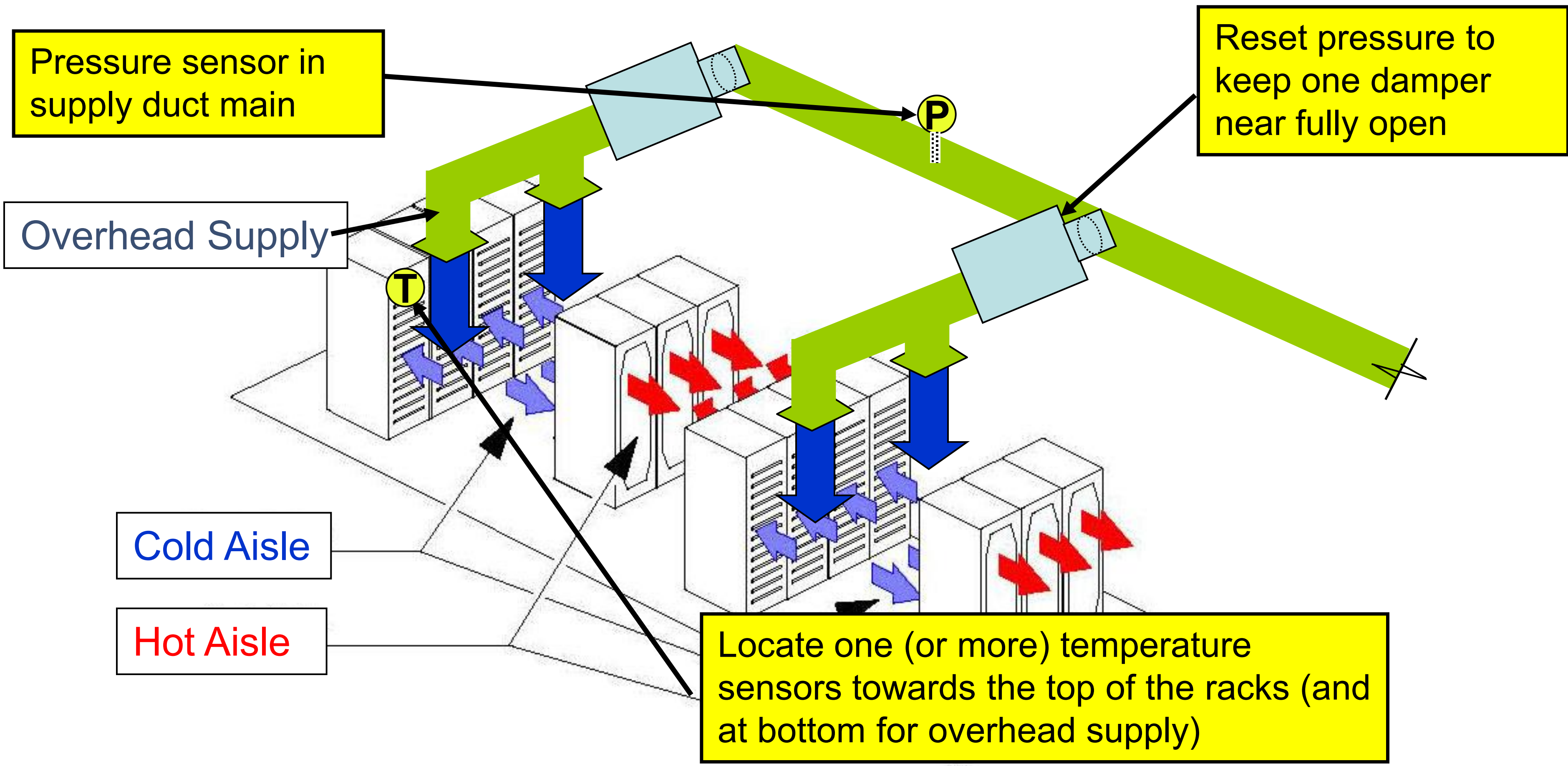
Example Grouping by CRAH



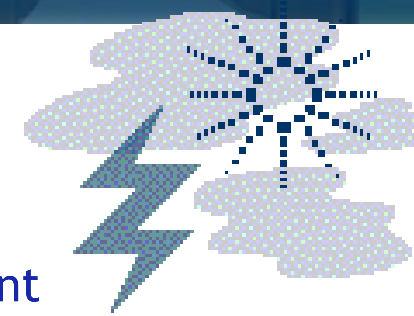
Airflow controls overhead

- All headered supply fans controlled to same speed
- Set speed to maintain pressure in supply header
- Control dampers to maintain racks at temperature
- Reset pressure setpoint and supply temperature to keep most open damper at or near fully open

Control sensors overhead



Humidity control



- Avoid if at all possible
  - High humidity is usually limited by cooling coil dew-point temperature.
  - Low humidity limit is not well supported (see previous slides).
- If you decide to humidify, do all of the following:
  - Use high quality dew-point sensors located in the data center floor (Vaisala see NBCIP report: http://www.buildingcontrols.org/publications.html).
  - Use adiabatic (not steam or infrared) humidifiers.
    - Direct Evaporative Media.
    - Ultrasonic (but note that DI or RO water is required)
  - Best to provide on MUA unit.
  - Control all humidifiers together if distributed.

Example survey of CRACs

	Vaisala Probe			CRAC Unit Panel			
	Temp	RH	Tdp	Temp	RH	Tdp	Mode
AC 005	84.0	27.5	47.0	76	32.0	44.1	Cooling
AC 006	81.8	28.5	46.1	55	51.0	37.2	Cooling & Dehumidification
AC 007	72.8	38.5	46.1	70	47.0	48.9	Cooling
AC 008	80.0	31.5	47.2	74	43.0	50.2	Cooling & Humidification
AC 010	77.5	32.8	46.1	68	45.0	45.9	Cooling
AC 011	78.9	31.4	46.1	70	43.0	46.6	Cooling & Humidification
Min	72.8	27.5	46.1	55.0	32.0	37.2	
Max	84.0	38.5	47.2	76.0	51.0	50.2	
Avg	79.2	31.7	46.4	68.8	43.5	45.5	

Feedback and diagnostics

- Normal Indices
  - SAT (or RAT)
  - CHWS
  - Equipment Status
  - Space Temp
  - Space RH (or return RH)
- Improved Indices
  - Rack Cooling Index (see next slide)
  - Plant kW/ton
  - LBNL's Data Center Metric Phvac/Pservers
  - Most open valve status (and location)
  - Most open damper status (and location)
  - Air management

$$\frac{\Delta T_{ACs/AHUs}}{\Delta T_{Servers}} = \text{Return Temperature Index (RTI)}$$

Rack cooling indices

$$RCI_{HIGH} = \left(1 - \frac{\sum_i (T_i - 77)}{n \times (90 - 77)}\right) X100\%$$

$$RCI_{LOW} = \left(1 - \frac{\sum_j (68 - T_j)}{n \times (68 - 59)}\right) X100\%$$

Herrlin, M. K. 2005. Rack Cooling Effectiveness in Data Centers and Telecom Central Offices: The Rack Cooling Index (RCI). ASHRAE Transactions, Volume 111, Part 2, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

IT integration

- Control system server
  - Who provides it
  - Where is it located
- Control CRAC/CRAH/AHU based on IT temperature sensors – LBNL is doing a demonstration of this.
- Gateways
  - CRAC/H unit controls
  - VSDs
  - Electrical Panels

Other issues

- Power down restart sequences
- Control system redundancy (e.g. chillers)
  - Distributed controllers (one per chiller)
  - Redundant controllers (with heartbeat and transfer switches)
  - See Engineered Systems September 2007 Article “Mission Critical Building Automation.”
- Testing coordination
- Remote access/security

Best practice controls

- Use high quality sensors (not the ones that come with the CRAC/H units!).
- If used, locate the humidity sensor in the data center floor (not in the unit return).
- Reset temp and pressure by demand at racks.
- Avoid humidity controls if possible, if necessary provide it on MUA unit.
- Provide CRAC/H or AHUs with variable speed fans and control all fans in parallel to same speed.
- Used advanced whole system metrics to track system performance.
- Commission the controls thoroughly.

Break

Data Center Commissioning

Mark Hydeman, P.E., FASHRAE

Taylor Engineering

Who does commissioning?

- Contractor
  - Current practice
  - Largely ineffective due to competitive pressures, lack of oversight
- Design engineer
  - Most familiar with design, but often not sufficiently experienced with controls
  - Cx not included in standard fees
- 3rd Party
  - No conflict of interest, but most expensive and can be disruptive
- Combination of above
  - Split work among various parties to minimize cost, take advantage of expertise
- Cx Plan must be clearly detailed in spec’s!

Prefunctional tests

- Augments and documents manufacturer’s start up procedures for equipment
- Includes some system testing like
  - Pipe pressure testing
  - Duct leakage testing
  - Valve leakage tests
- May include factory witness testing (e.g. chillers)

Control system pre-functional tests

- General
  - Inspect the installation of all devices.
  - Verify integrity/safety of all electrical connections.
  - Verify that all sensor locations are as indicated on drawings
- Digital Outputs
  - Verify DOs operate properly and that the normal positions are correct.
- Digital Inputs
  - Adjust setpoints, where applicable.
- Analog Outputs
  - Verify start and span are correct and control action is correct.
- Analog Input Calibration
  - Calibrated as specified on the points list
  - Inaccurate sensors must be replaced if calibration is not possible.
- Gateway points (bi-directional)

Functional tests

- Scope
  - Test every sequence
  - For data centers typically we test every piece of equipment
- Format
  - Test form to include setup, steps, expected response, and actual response

Functional tests

I. Chilled Water Pumping System

The following is from the specifications for bypass valve, minimum flow control:

<u>Chiller Stage</u>	<u>Chillers operating</u>	<u>Minimum Flow</u>
1	1 small, 0 big	250
2	2 small, 0 big	480
3	1 small, 1 big	595
4	2 small, 1 big	825
5	1 small, 2 big	940
6	2 small, 2 big	1,170
7	3 small, 2 big	1,400
8	4 small, 2 big	1,605

The following is from the specifications for pump staging:

CHW Pumps Operating	Nominal flow	Stage up to this stage if flow exceeds this for 5 minutes	Stage down to lower stage if flow is below this for 5 minutes*
1	650 gpm	--	--
2	1,300 gpm	650 gpm	490 gpm
3	1,950 gpm	1,300 gpm	975 gpm
4	2,600 gpm	1,950 gpm	1,450 gpm

<u>Unit(s) Tested:</u>		**<u>Tested by: Mark P & Gary K.</u>**	
<u>Action</u>	**<u>Expected Response</u>**	**<u>Observed Response</u>**	**<u>Date/Time</u>**
At the chillers and the EMCS system, read and record the flowrates from each of the operating chillers. Read and record the EMCS calculated plant flowrate. **Chillers were locked on.**	The plant flow rate should equal the sum of the flow meters on all of the operating chillers The EMCS flow rate should	Flowrates (gpm) At Meter	At EMCS CH-1: **245.1**	**245.5** CH-2: **274.0**	**274.5** CH-3: **124.6**	**124.6** CH-4: **off**	**off**	11/16/06 3:23pm

Functional tests

Unit(s) Tested:		Tested by: Mark P & Gary K.	
Action	**Expected Response**	**Observed Response**	**Date/Time**
	match the flowrate on the faceplate of the flow meters	CH-5: **off** | **off** CH-6: **off** | **off** Plant: ----N/A------|	
For each pump, read and record the minimum speed setpoint in the drive **20% ---100% BAS** **20Hz----60Hz VFD**	Either the VSD minimum or the EMCS minimum should be 0. The other should be set to 10% (6HZ)	Minimum setting VSD EMCS P-1: **20Hz** | **20%** P-2: **20Hz** | **20%** P-3: **20Hz** | **20%** P-4: **20Hz** | **20%**	11/16/06 3:30pm
Read and record the following data: • Total plant flowrate (EMCS, gpm) • Current DP setpoint (EMCS, psi) • Current DP at the sensors in the distribution loop (EMCS, psi) • Which pumps are running • Current pump speeds (both at the EMCS and on the VSD panel) At the EMCS increase the DP setpoint by 10% to 15%. Wait 3 minutes. Read and record the following data: • Total plant flowrate (EMCS, gpm) • Current DP setpoint (EMCS, psi) • Current DP at the sensors in the distribution loop (EMCS, psi)	DP sensor reading should be stable at DP sensor setpoint. The VSD should have sped up to get the DP sensor reading to the new setpoint. There should be no hunting of the VSD speed or actual loop pressure. The plant flow rate should not change appreciably. The number of pumps running should be as follows: • 1 for flow between 0 and 490 gpm • 1 or 2 for flow between	**As-is data** Plant flowrate: **637.5** DP setpoint: **15#** DP reading 1: **14.8 #** DP reading 2: **NA** Pump Speeds/Status (0=OFF) VSD EMCS P-1: **49.9** | **83.5** P-2: **0** | P-3: **0** | P-4: **0** | **Post setpoint change data** Plant flowrate: **695.8** DP setpoint: **17.0** DP reading 1: **16.5** DP reading 2: **NA** Pump Speeds/Status (0=OFF)	

More functional tests

- Shut off devices and watch system response (e.g. start of backup pump)
- Check alarms and response
- Override setpoints and watch system response
- Push system to extremes (requires load banks)
- Power system down and check recovery
- Check control system panel failure (if designed for redundancy)
- Power down restart sequences
- Observe system as it operates

Trend reviews

- Required even when detailed functional tests are performed
  - Functional tests mimic control sequences – they prove programming matches sequences but cannot identify bugs in sequences
- Less expensive than comprehensive functional testing with proper analysis tools
  - But trends do not generally show faults – they must be tested in the field since they may not occur during trend period
- Requires experienced eye – design engineer with controls experience who is very familiar with sequences and HVAC systems

Other Cx issues

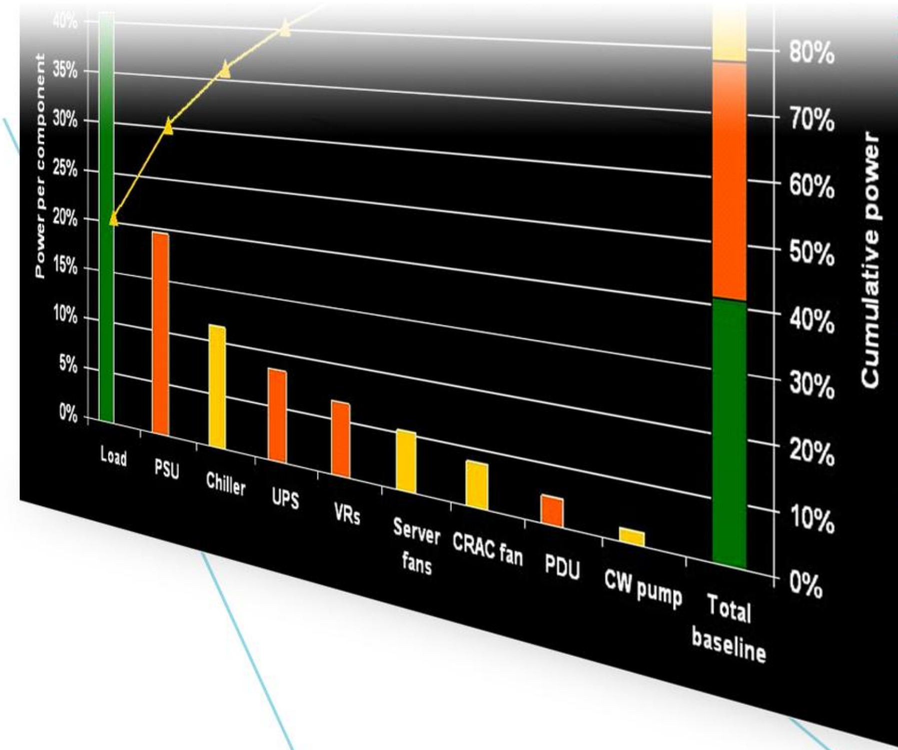
- One person on site must coordinate all Cx activities
- Hold regular weekly Cx meetings
- Coordination of load banks with electrical
- Detail recovery procedures for testing on live data centers
- Carefully coordinate electrical, mechanical and control testing to save time and costs
  - Mechanical and control testing in general should not overlap electrical system testing

Best practices for Cx

- Specify thorough commissioning for data centers
- Be specific on roles and responsibilities
- Have an experienced Cx coordinator on the site
- Hold weekly Cx meetings with all trades represented
- Carefully coordinate electrical, mechanical and control system testing

Take aways

- No “right” way to perform commissioning
- Comprehensive Cx involves many steps
- Various approaches—contractor, engineer, 3rd party, combo
- Commissioning plan must be in specifications
- Controls programming should be reviewed
- Prefunctional and functional tests verify system and component function
- Trend reviews while not as comprehensive can identify problems
- Coordination is important during commissioning



Assessment Tools and Protocols

Bill Tschudi, PE

Berkeley Lab

Steps to saving energy:

Energy Profiling
↓
Subsystem Assessment

- Assessments conducted by owners and engineering firms using DOE tools
- Tools provide uniform metrics and approach

↓
Detailed Engineering Audit
↓
Engineering Design
↓
Retrofit/RCx Implementation

- Audits, design and implementation by engineering firms and contractors

↓
Savings Validation (M&V)
↓
Documentation

- M&V by site personnel and eng firms
- DOE tools used to document results, track performance improvements, and disseminate best practices

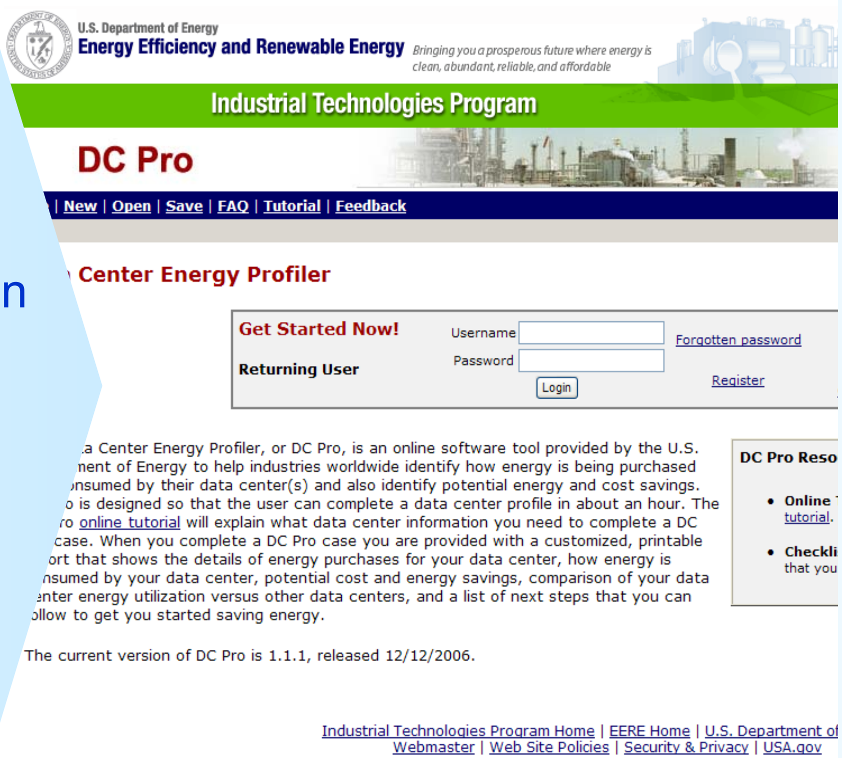
DOE tool suite: DC Pro

- Profiling Tool: profiling and tracking
  - Establish DCIE baseline and efficiency potential (few hours effort)
  - Document actions taken
  - Track progress in DCiE over time
- Assessment tools: more in-depth site assessments
  - Suite of tools to address major sub-systems
  - Provides savings for efficiency actions
  - ~2 week effort (including site visit)

Online profiling tool

INPUTS

- Description
- Utility bill data
- System information
  - IT
  - Cooling
  - Power
  - On-site gen



OUTPUTS

- Overall efficiency (DCiE)
- End-use breakout
- Potential areas for energy efficiency improvement
- Overall energy use reduction potential

DC Pro profiling tool demonstration

www.eere.energy.gov/datacenters

DCPro Report - Berkeley Lab

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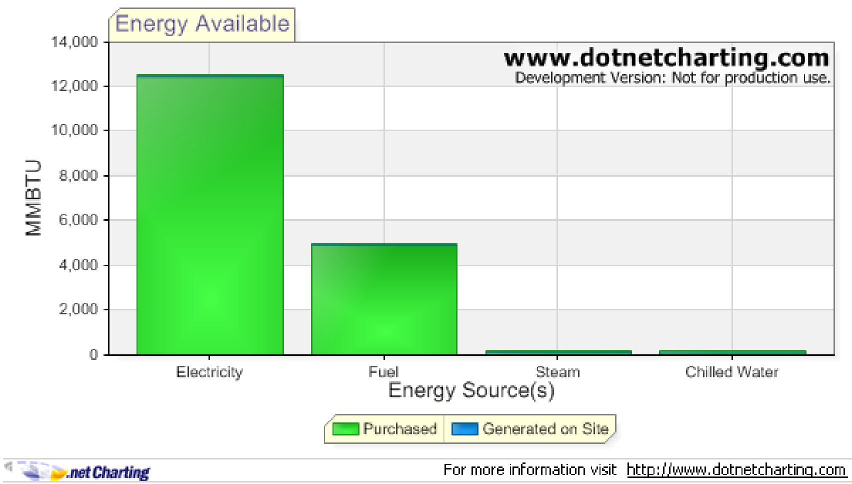
http://dcpro.ppc.com/DCProReport.aspx?step=&screen=1

Annual Energy Use



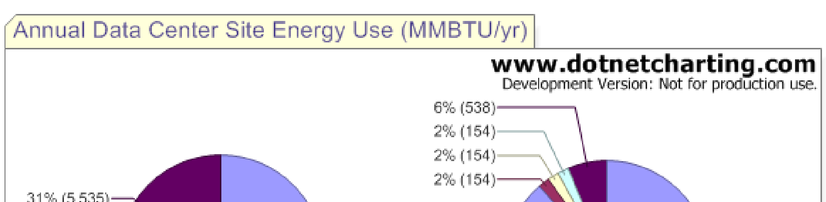
	Total Amount Generated On Site	Total Amount	Unit
Electricity	0	12,535	MMBTU/yr
Fuel	0	4,980	MMBTU/yr
Steam	0	176	MMBTU/yr
Chilled Water	0	160	MMBTU/yr
Total	0	17,851	MMBTU/yr

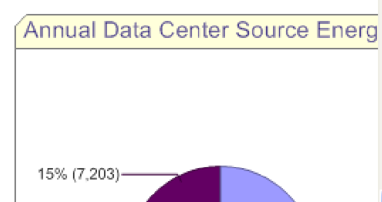
Potential Annual Energy Savings

Suggested Next Steps

The following chart and data table summarize your data center's potential annual energy savings by breakout catergory.
NOTE: The energy and money savings listed below are only estimates based on the data you entered and the estimated costs associated with the data center su

Breakout Category	Current Energy Use				Potential Energy Use				Potential Sa
	Site Energy		Source Energy		Site Energy		Source Energy		
	MMBTU/yr	%	MMBTU/yr	%	MMBTU/yr	%	MMBTU/yr	%	MMBTU/yr
IT Equipment	7,689	43%	25,872	54%	7,689	88%	25,872	88%	0
Data Center Lights	826	5%	2,779	6%	154	2%	517	2%	672
Electric Distribution Losses	1,501	8%	5,052	11%	154	2%	517	2%	984
Fans	2,140	12%	7,201	15%	154	2%	517	2%	1,623
Cooling	5,535	31%	7,203	15%	538	6%	1,811	6%	3,724
Total	17,691	100%	48,107	100%	8,688	100%	29,236	100%	7,003
DCIE		0.43		0.54		0.88		0.88	





DCPro Report - Berkeley Lab

http://dcpro.ppc.com/DCProReport.aspx?step=&screen=1

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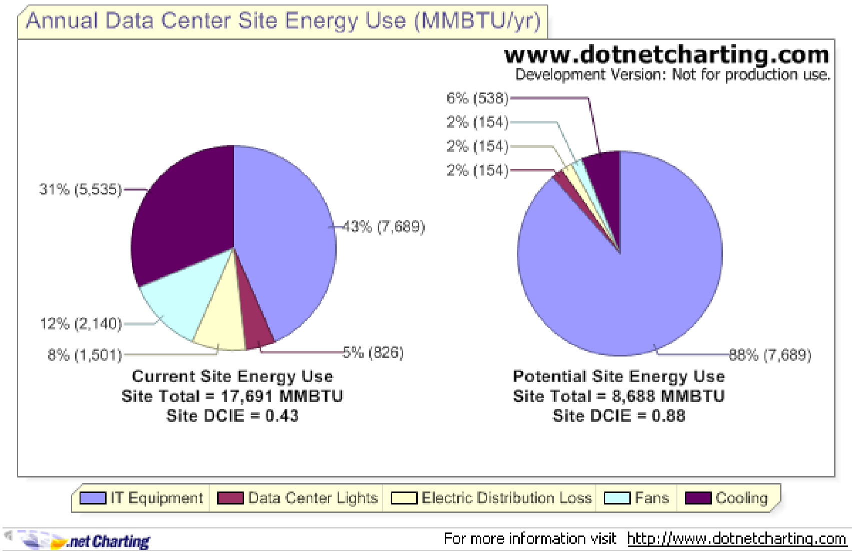

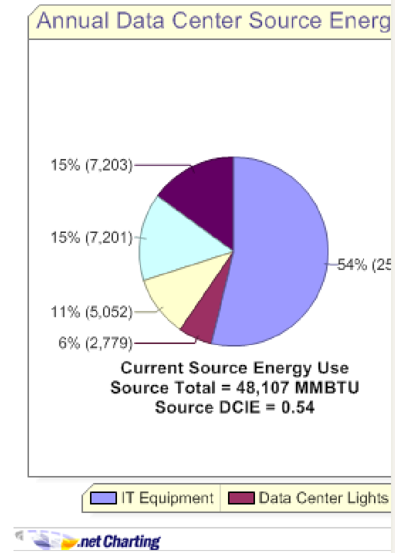

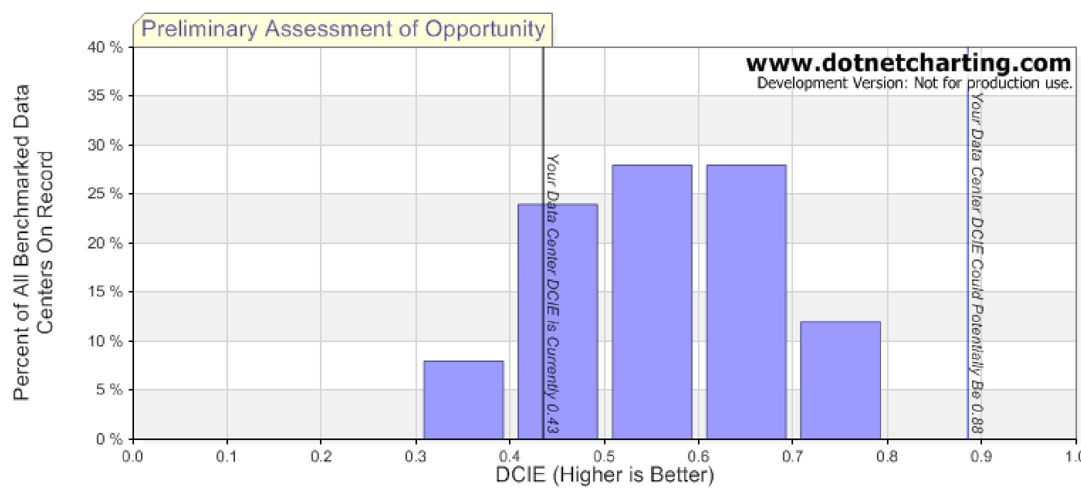

DCPro Report - Berkeley Lab

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http://dcpro.ppc.com/DCProReport.aspx?Step=ECOND&screen=2

County	Carroll County
State	Georgia

Suggested Next Steps   Potential Annual Savings

Energy Management | IT Equipment | Environmental Conditions | Air Management | Cooling Plant | IT Equipment Power Chain | Lighting | Global Action

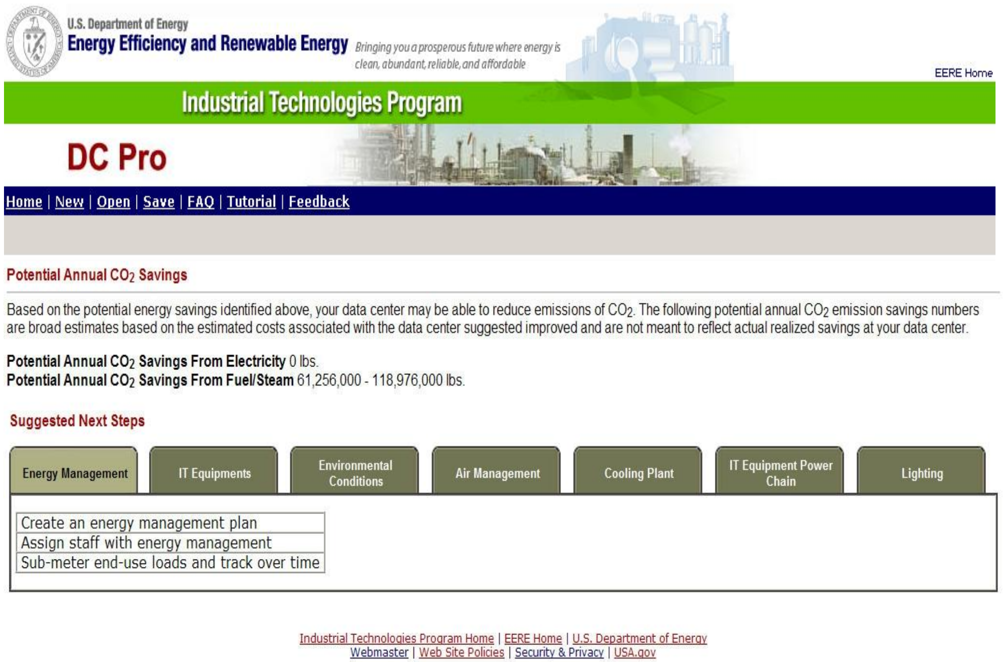
EC.A.1	Consider Air-Management measures	A low air temperature rise across the data center and/or IT equipment intake temperatures outside the recommended range suggest air management problems. A low return temperature is due to by-pass air and an elevated return temperature is due to recirculation air. Estimating the Return Temperature Index (RTI) and the Rack Cooling Index (RCI) will indicate if corrective, energy-saving actions are called for.
EC.A.2	Consider increasing the supply temperature	A low supply temperature makes the chiller system less efficient and limits the utilization of economizers. Enclosed architectures allow the highest supply temperatures (near the upper end of the recommended intake temperature range) since mixing of hot and cold air is minimized. In contrast, the supply temperature in open architectures is often dictated by the hottest intake temperature.
EC.A.4	Place temperature/humidity sensors so they mimic the IT equipment intake conditions	IT equipment manufacturers design their products to operate reliably within a given range of intake temperature and humidity. The temperature and humidity limits imposed on the cooling system that serves the data center are intended to match or exceed the IT equipment specifications. However, the temperature and humidity sensors are often integral to the cooling equipment and are not located at the IT equipment intakes. The condition of the air supplied by the cooling system is often significantly different by the time it reaches the IT equipment intakes. It is usually not practical to provide sensors at the intake of every piece of IT equipment, but a few representative locations can be selected. Adjusting the cooling system sensor location in order to provide the air condition that is needed at the IT equipment intake often results in more efficient operation.
EC.A.5	Recalibrate temperature and humidity sensors	Temperature sensors generally have good accuracy when they are properly calibrated (+/- a fraction of a degree), but they tend to drift out of adjustment over time. In contrast, even the best humidity sensors are instrinsically not very precise (+/- 5% RH is typically the best accuracy that can be achieved at reasonable cost). Humidity sensors also drift out of calibration. To ensure good cooling system performance, all temperature and humidity sensors used by the control system should be treated as maintenance items and calibrated at least once a year. Twice a year is better to begin with. After a regular calibration program has been in effect for a while, you can gauge how rapidly your sensors drift and how frequent the calibrations should be. Calibrations can be performed in-house with the proper equipment, or by a third-party service.
EC.A.6	Network the CRAC/CRAH controls	CRAC/CRAH units are typically self-contained, complete with an on-board control system and air temperature and humidity sensors. The sensors may not be calibrated to begin with, or they may drift out of adjustment over time. In a data center with many CRACs/CRAHs it is not unusual to find some units humidifying while others are simultaneously dehumidifying. There may also be significant differences in supply air temperatures. Both of these situations waste energy. Controlling all the CRACs/CRAHs from a common set of sensors avoids this.
EC.A.8	Consider disabling or eliminating humidification controls or reducing the humidification setpoint	Tightly controlled humidity can be very costly in data centers since humidification and dehumidification are involved. A wider humidity range allows significant utilization of free cooling in most climate zones by utilizing effective air-side economizers. In addition, open-water systems are high-maintenance items.
EC.A.9	Consider disabling or eliminating dehumidification controls or increasing the dehumidification setpoint	Most modern IT equipment is designed to operate reliably when the intake air humidity is between 20% and 80% RH. However, 55% RH is a typical upper humidity level in many existing data centers. Maintaining this relatively low upper limit comes at an energy cost. Raising the limit can save energy, particularly if the cooling system has an airside economizer. In some climates it is possible to maintain an acceptable upper limit without ever needed to actively dehumidify. In this case, consider disabling or removing the dehumidification controls entirely.
EC.A.10	Change the type of humidifier	Most humidifiers are heat based; ie, they supply steam to the air stream by boiling water. Electricity or natural gas are common fuel sources. The heat of the steam becomes an added load on the cooling system. An evaporative humidifier uses much less energy. Instead of boiling water, it introduces a very fine mist of water droplets to the air stream. When set up properly the droplets quickly evaporate, leaving no moisture on nearby surfaces. This has an added cooling benefit, as the droplets absorb heat from the air as they evaporate.

Previous   Save & Continue

Example "DC Pro" recommendations

List of Actions (for Electric Distribution System)

- Avoid lightly loaded UPS systems
- Use high efficiency MV and LV transformers
- Reduce the number of trans-formers upstream and down-stream of the UPS
- Locate transformers outside the data center
- Use 480 V instead of 208 V static switches (STS)
- Specify high-efficiency power supplies
- Eliminate redundant power supplies
- Supply DC voltage to IT rack



DC Pro tools

High Level Profiling Tool

- Overall energy performance (baseline) of data center
- Performance of systems (infrastructure & IT) compared to benchmarks
- Prioritized list of energy efficiency actions and their savings, in terms of energy cost ($), source energy (Btu), and carbon emissions (Mtons)
- Points to more detailed system tools

IT Module
- Servers
- Storage & networking
- Software

Cooling
- Air handlers/ conditioners
- Chillers, pumps, fans
- Free cooling

Air Management
- hot cold separation
- environmental conditions

Power Systems
- UPS
- Transformers
- Lighting
- Standby gen.

On-Site Gen
- Renewables
- use of waste heat

Data confidentiality

- All input data is treated as confidential
- Data in benchmarking charts are "anonymized" with random facility ID numbers
- Data is saved to a secure database server and can not be accessed by the general public

Assessment worksheet

- List of metrics and features
  - Priorities for metrics
  - Data required
- Data collection template
- List of actions

Data Center Assessment Inputs: Features and Metrics
DRAFT 1-24-08

Notes:
1. Each assessment area has two types of inputs: features and metrics
2. The features checklist can be used for stage 1 assessment (prior to site visit), and to prioritize metrics for stage 2 assessment
3. Input fields are shaded in blue - defaults are provided for priorities
4. Priority levels for metrics: 1 - Must have; 2 - Important, subject to ease of data collection; 3 - collect only if easily available

1. Overall Energy Management				
Has an audit or commissioning been conducted within the last 2 years?				
Is there a written energy management plan?				
Are there staff with explicit energy management responsibility?				
What is the redundancy level for Electrical systems? (N, N+x, 2N)				
What is the redundancy level for HVAC systems? (N, N+x, 2N)				
What is the current usage factor? (% of space?)				
Metrics	*Unit*	*Data Required*	*Priority*	*Value*
Overall Energy Effectiveness (IT energy use / total energy use)	-	IT Equipment Energy Use Total DC Energy Use (Site)	1	
Site Energy Use Intensity	Site BTU/sf-yr	Total DC Energy Use (Site) DC Floor Area	2	
Source Energy Use Intensity	Source BTU/sf-yr	Total DC Energy Use (Source) DC Floor Area	3	
Purchased Energy Cost Intensity	Energy $/sf-yr	Total DC Energy Cost DC Floor Area	2	
Peak Electrical Load Intensity	Peak W/sf	Total DC Peak Elec Demand DC Floor Area	2	
2. Environmental Conditions				
What are the temperature setpoints (specify range)?				
What are the humidity setpoints (specify range)?				
Recommended and allowable intake temperatures and humidity (specify ranges)?				
Where are temperature and humidity sensors located (return, other)?				
Do CRAC/CRAH units have centralized or distributed controls?				
Are there humidity controls and does the data center need humidity control?				
Are there procedures and personnel/cable grounding equipment to prevent ESD?				
Are unit controls fighting each other (for example, simultaneously humidifying and dehumidifying)?				
Does system have capability of taking slope and offset for sensor recalibration?				
Metrics	*Unit*	*Data Required*	*Priority*	*Value*
Ratio Max Density to Average Heat Density	None	Max Heat Density Average Heat Density	2	
Actual Dew-Point Temperature	F	Data Center Dewpoint Temperature	1	
Climate Data	F	TMY/TRY/WYEC data	1	
Temperature and humidity sensor calibration	Slope and offset	Reference sensor reading	1	
3. Air Management, CRAC/CRAH/AHU				
How many CRAC/CRAH/AHUs are there? Identify which operate under normal conditions and which are standby.				
For each CRAC/CRAH/AHU collect nameplate data for unit, for each motor and submittal data identifying capacity and design conditions.				
What is the clear ceiling in feet (slab to slab minus raised floor minus dropped ceiling)?				
Is there a ceiling return plenum? If yes, what is the height and static pressure?				
Is there a floor supply plenum (raised floor)? If yes, what is the height and static pressure?				
What is the estimated floor leakage in percent of total system airflow?				
Where are cables and pipes located?				

Contact information

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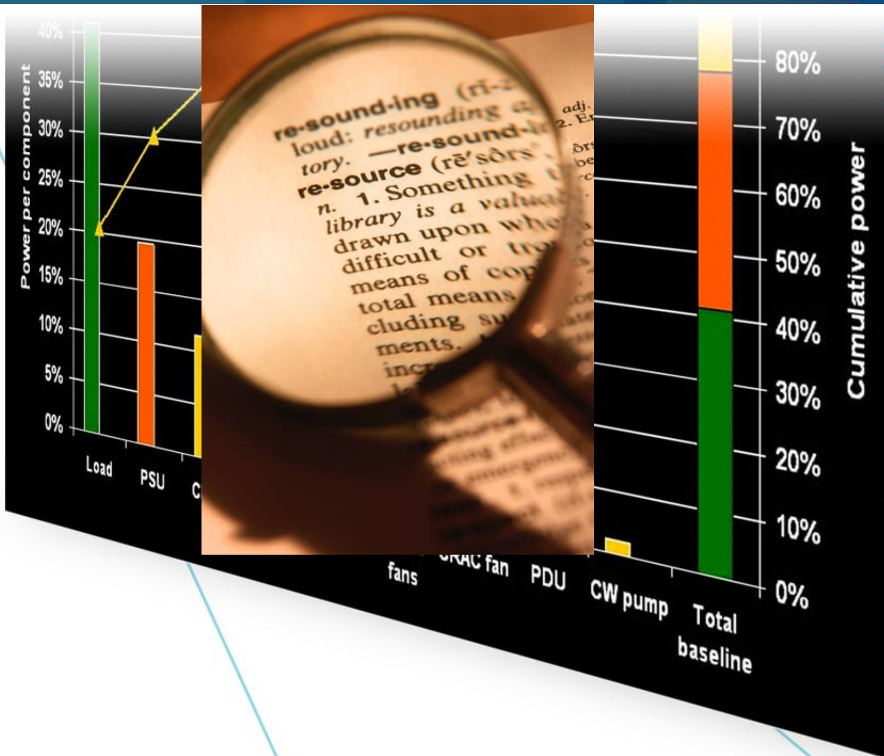

Resources

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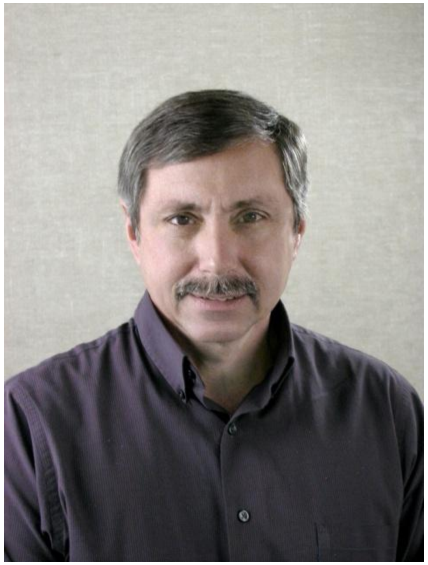


Links for more information

DOE EERE Technical Assistance Project:
http://apps1.eere.energy.gov/wip/tap.cfm

DOE Website: Sign up to stay up to date on new developments
www.eere.energy.gov/datacenters

Lawrence Berkeley National Laboratory (LBNL)
http://hightech.lbl.gov/datacenters/

ASHRAE Data Center technical guidebooks
http://tc99.ashraetcs.org/

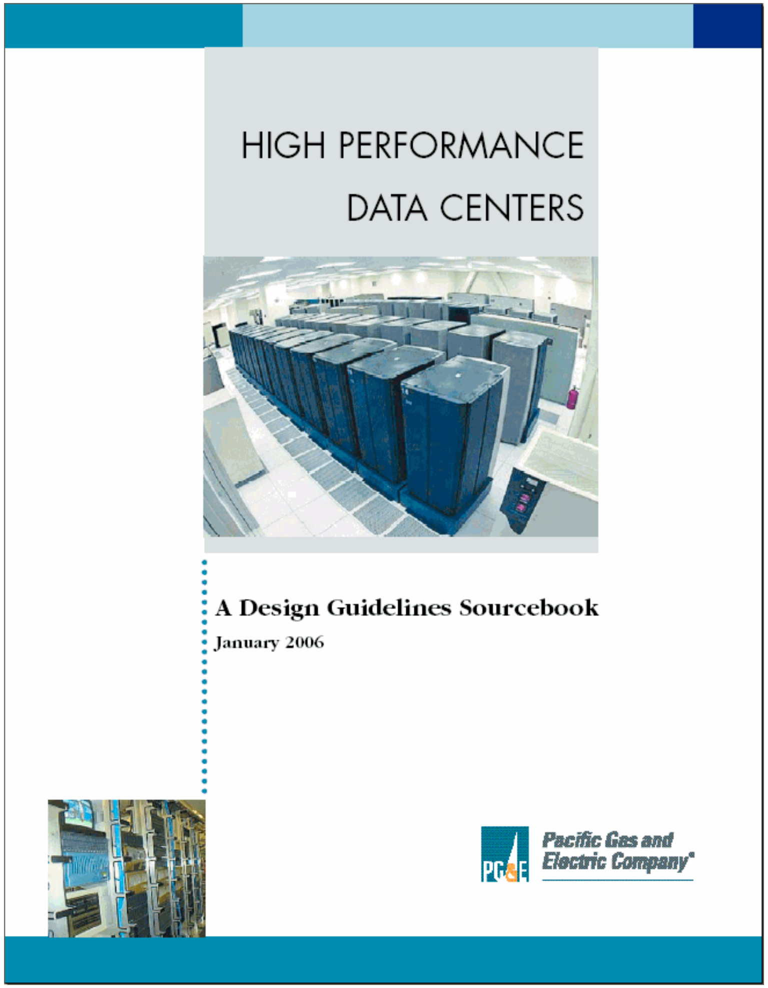
The Green Grid Association: White papers on metrics
http://www.thegreengrid.org/gg_content/

Energy Star® Program
http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency

Uptime Institute white papers
www.uptimeinstitute.org

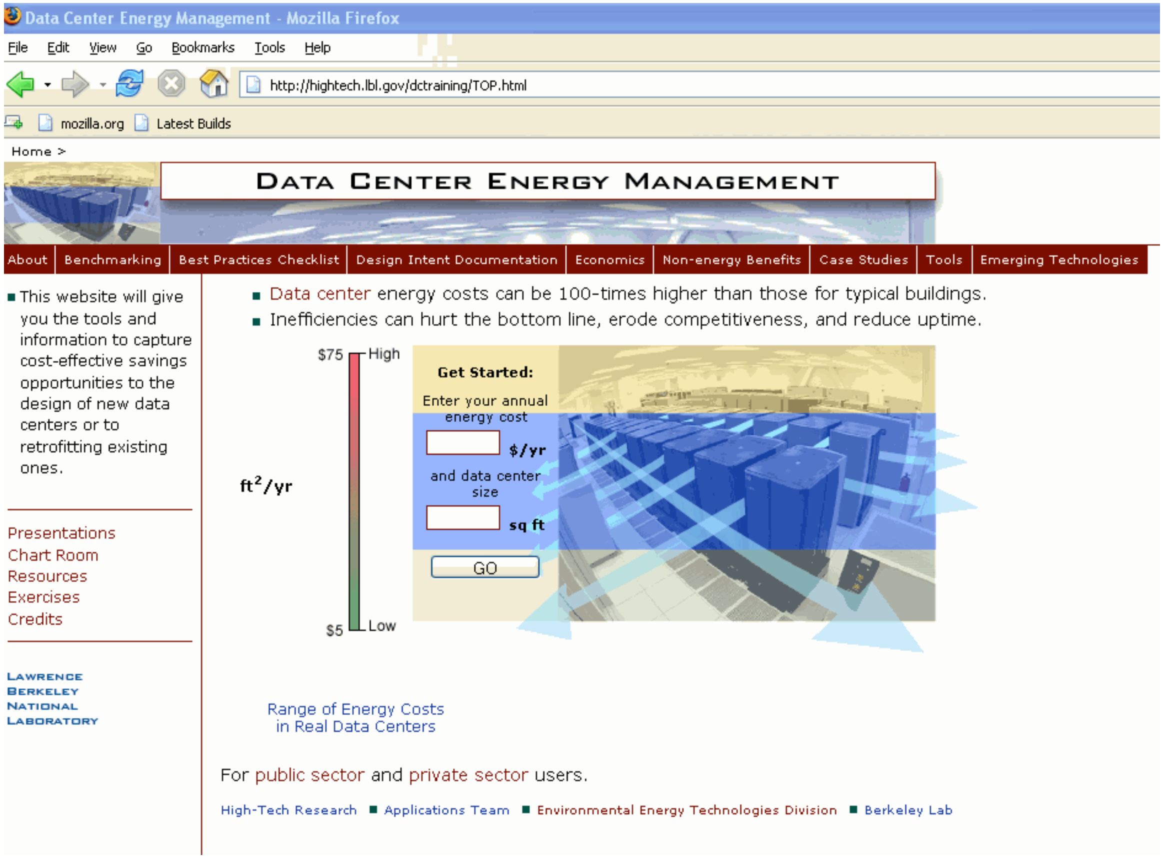
Design guidelines are available

- Design Guides were developed based upon observed best practices
- Guides are available through PG&E and LBNL websites



http://hightech.lbl.gov/documents/DATA_CENTERS/06_DataCenters-PGE.pdf

Web based training resource



http://hightech.lbl.gov/dctraining/TOP.html

ASHRAE Datacom series

Order from http://tc99.ashraetcs.org/

ASHRAE resources

- ASHRAE (http:\\www.ashrae.org)
  - Technical Committee (TC) 9.9 Mission Critical Facilities http://tc99.ashraetcs.org/

Server System Infrastructure

Managing Component Interfaces

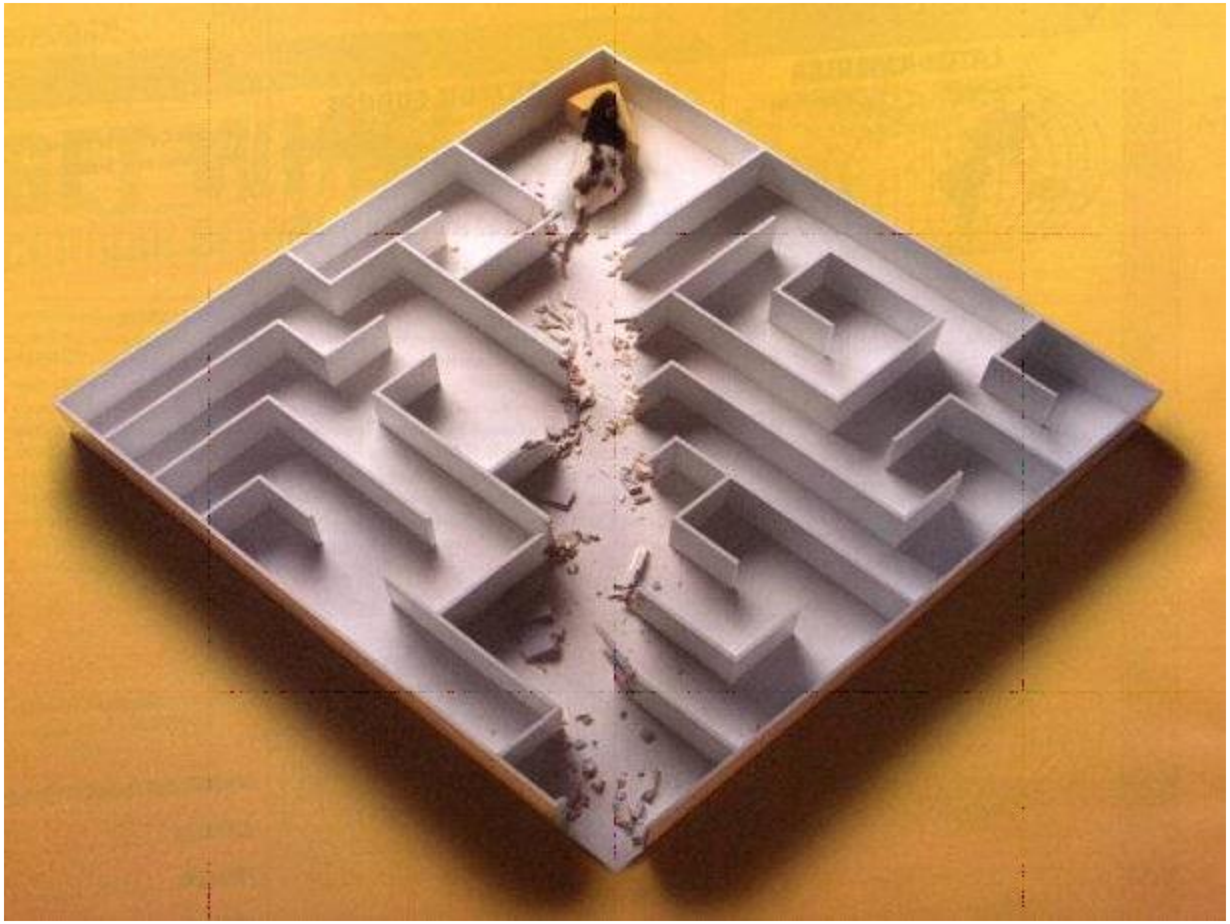
80 PLUS

www.ssiforums.org
www.80plus.org

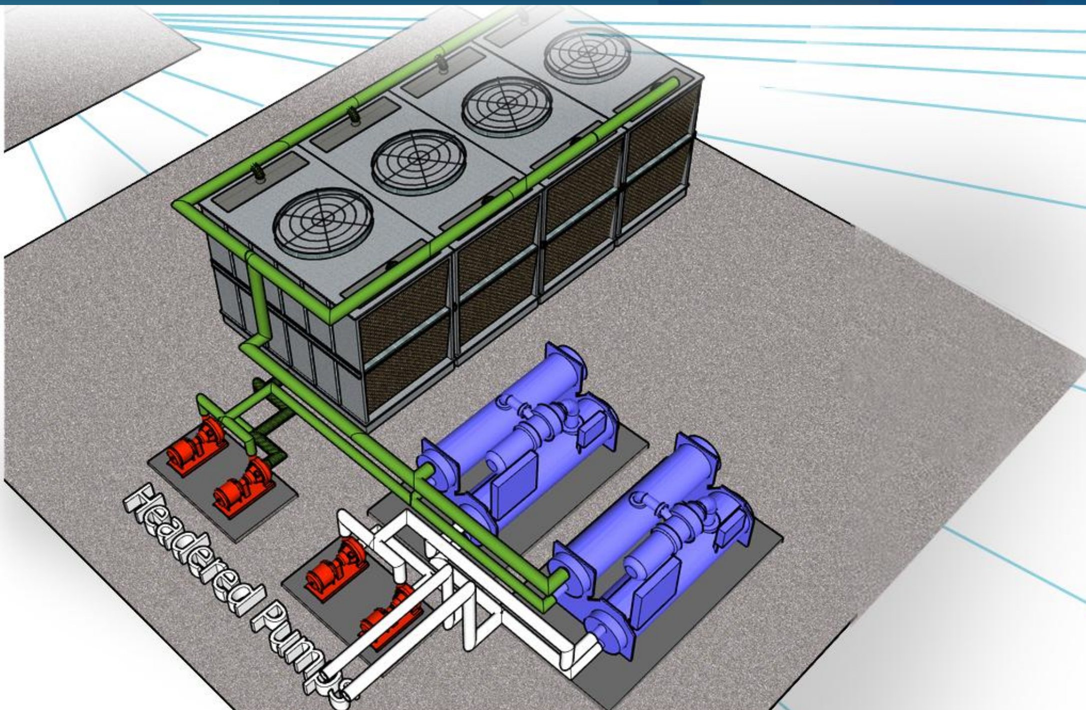
Other resources

- Electrostatic Discharge Association (http://www.esda.org/)
- Uptime Institute (http://www.upsite.com/TUIpages/tuihome.html)
- Green Grid (http://www.thegreengrid.org/home)
- Chilled Water Plant Resources
  - PG&E CoolTools™ Chilled Water Plant Design Guide (http://taylor-engineering.com/publications/design_guides.shtml)
  - ASHRAE Journal article, "Balancing Variable Flow Hydronic Systems" and other CHW articles on TE website at http://www.taylor-engineering.com/publications/articles.shtml
- Control and Commissioning Resources
  - DDC Online (http://www.ddc-online.org)
  - AutomatedBuildings (http://www.automatedbuildings.com/). This site is an e-zine on building automation and controls.
  - ASHRAE Guideline 13-2000, "Specifying Direct Digital Control System."
  - Control Spec Builder an on-line resource for developing control specifications (http://www.CtrlSpecBuilder.com)
  - National Building Controls Information Program (NBCIP, http://www.buildingcontrols.org/)
  - CSU Control and CX Guidelines (http://www.calstate.edu/cpdc/ae/guidelines.shtml)
  - California Commissioning Collaborative (CaCx, http://www.cacx.org)

Questions? - Discussion



Thank you for attending



Air System Design

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